

UNIVERSITÀ DEGLI STUDI DI GENOVA



**Dipartimento di Ingegneria navale, elettrica, elettronica e delle telecomunicazioni
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Sistemi Complessi per la Mobilità - Sistemi di trasporto marittimi e marini

LNG Small Scale Bunkering Services - La Spezia Port case study: potential scenarios for LNG supply, associated costs, energy consumption, GHGs and air pollutants for different transport modes.

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Executive summary

Emission Control Areas (ECAs) in EU waters already have imposed a 0.1% sulphur cap and last year IMO has set a global limit for sulphur in fuel oil used on board ships of 0.50% m/m (mass by mass) from 1 January 2020, which enforces the cap already applicable in EU waters under the Sulphur Directive.

It is widely recognized that the use of liquefied natural gas (LNG) instead of conventional residual and distillate fuels will substantially reduce emissions of oxides of nitrogen (NO_x), sulphur dioxide (SO₂), and particulate matter (PM). Nonetheless, considerable uncertainty remains about the net effects of LNG-fuelled vessels on emissions. At issue are the upstream greenhouse gas (GHG) emissions (mainly CO₂ and methane) impacts of LNG, including the energy required to transport and handle the fuel as well as the leakage of natural gas into the atmosphere, which are highly pathway-specific and should be taken into account when a supply chain for Small Scale LNG bunkering is to be set up.

As of 2014, the Alternative Fuels Infrastructure Directive (AFID) requires Member States to ensure, by means of their National Policy Frameworks (NPF), that an appropriate number of refuelling points for LNG are put in place at maritime ports, to enable LNG seagoing ships to circulate throughout the TEN-T Core Network by 31 December 2025. Following DAFI Adoption, Italy has transposed the Directive in its legislative framework (D.lgs. 257/2016), developed the NPF for natural gas deployment and launched the GAINN_IT Initiative, coordinated by the Italian Ministry of Transport and Infrastructure, with the aim of conceiving, defining, prototyping, testing, validating and deploying, in the period 2017-2030, the Italian Network of Infrastructures of Alternative Fuels (LNG in particular) for maritime and surface transport as requested by AFID. Both the Italian NPF for LNG deployment and the GAINN_IT Initiative identified the Tyrrhenian-Ligurian grid (embracing the Core Ports of Genoa, La Spezia and Livorno) as one of the three grids in Italy for the deployment of LNG as alternative shipping fuel through dedicated supply and distribution facilities.

Within this framework, this paper stems from the knowledge and experience gained within the course of EU-funded trans-national projects and focused on investigating the critical aspects (from an environmental, energy and economic point of view) of the LNG supply chain for a defined case study, namely the Port of La Spezia (Italy). The local context has been investigated in terms of existing assets, applicable regulations and logistic constraints. The potential demand for LNG in the Port of La Spezia has been considered and elaborated grounding on publicly available data and model validated within the GAINN_IT Initiative. The existing SNAM owned and GNL Italia operated regasification terminal of Panigaglia has been analysed in detail, evaluating the upgrading needed to provide Small Scale LNG services in an evolving framework, while elaborating location and sizing hypotheses for an alternative modular LNG storage layout within the Port of La Spezia.

Different scenarios for ensuring adequate supply to cover the entire LNG demand have been studied considering the existing supply sources in Europe, resulting in simulations on costs and transit time for supplying of LNG from selected terminals of origin and assessments of supplying of LNG by barge from Panigaglia or by tanker from international terminals through different pathways.

Supplying scenarios related the latest evolutions in terms of LNG infrastructure deployment at national level have been then considered, serving as a basis for undertaking simulations on the energy consumption, GHGs and air pollutants emissions generated to supply La Spezia from both existing and suitable planned terminals.

As a result, the paper looks into the overall aspects of the small scale LNG chain in the Port of La Spezia from a technical, energy, environmental and economical point of view, providing insights to further detailed industrial studies aimed at setting up the most suitable supply chain for LNG deployment in the area.

1 Introduction

1.1 *Regulatory framework for maritime alternative fuels infrastructure deployment*

1.1.1 *IMO's MARPOL Convention Annex VI*

IMO is a specialized agency of the United Nations. It has responsibility for the regulation of international shipping, in particular for the safety of life at sea and the prevention of marine pollution.

IMO has been working to reduce harmful impacts of shipping on the environment since the 1960s, and the International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of operational or accidental pollution of the marine environment by ships.

Annex VI to the MARPOL Convention was adopted in 1997, to address air pollution from shipping. The regulations for the Prevention of Air Pollution from Ships seek to control airborne emissions from ships (sulphur oxides (SO_x), nitrogen oxides (NO_x), ozone depleting substances (ODS), volatile organic compounds (VOC) and shipboard incineration) and their contribution to local and global air pollution, human health issues and environmental problems. Annex VI entered into force on 19 May 2005 and a revised Annex VI with significantly strengthened requirements was adopted in October 2008.

These regulations entered into force on 1 July 2010 and introduced a global limit for sulphur content of ships' fuel oil, with tighter restrictions in designated emission control areas. Since 2010, further amendments to Annex VI have been adopted, including amendments to introduce further Emission Control Areas and progressive reductions in NO_x emissions from marine diesel engines installed on ships, with a "Tier II" emission limit for engines installed on a ship constructed on or after 1 January 2011¹; and a more stringent "Tier III" emission limit for engines installed on a ship constructed on or after 1 January 2016 operating in Emission Control Areas (ECAs). Additionally, energy efficiency requirements² entered into force in 2013.

1 Marine diesel engines installed on a ship constructed on or after 1 January 1990 but prior to 1 January 2000 are required to comply with "Tier I" emission limits, if an approved method for that engine has been certified by an Administration.

2 The Energy Efficiency Design Index (EEDI) was made mandatory for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships at MEPC 62 (July 2011) with the adoption of amendments to MARPOL Annex VI ([resolution MEPC.203\(62\)](#)), by Parties to MARPOL Annex VI. This was the first legally binding climate change treaty to be adopted since the Kyoto Protocol. More information can be found at: <http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Technical-and-Operational-Measures.aspx>

The limits introduced apply to all fuel oil, combustion equipment and devices onboard and therefore include both main and all auxiliary engines together with items such as boilers and inert gas generators. These controls divide between those applicable inside [ECAs](#) established to limit the emission of SO_x and particulate matter, and those applicable outside such areas and are primarily achieved by limiting the maximum sulphur content of the fuel oils as loaded, bunkered, and subsequently used onboard.

At the time of writing the ECAs established are:

1. Baltic Sea area – as defined in Annex I of MARPOL (SO_x only);
2. North Sea area – as defined in Annex V of MARPOL (SO_x only);
3. North American area (entered into effect 1 August 2012) – as defined in Appendix VII of Annex VI of MARPOL (SO_x, NO_x and PM); and
4. United States Caribbean Sea area (entered into effect 1 January 2014) – as defined in Appendix VII of Annex VI of MARPOL (SO_x, NO_x and PM).

These are regions where local ecological, oceanographic or vessel traffic patterns justify a higher level of protection from pollution³.

The fuel oil sulphur limits (expressed in terms of % m/m – that is by mass) are subject to a series of step changes over the years and are recapped as follows:

Outside an ECA established to limit SO _x and particulate matter emissions	Inside an ECA established to limit SO _x and particulate matter emissions
4.50% m/m prior to 1 January 2012	1.50% m/m prior to 1 July 2010
3.50% m/m on and after 1 January 2012	1.00% m/m on and after 1 July 2010
0.50% m/m on and after 1 January 2020	0.10% m/m on and after 1 January 2015

Table 1 – SO_x and PM emission limits and timing in/outside ECAs.

³ The Mediterranean Sea is not an ECA, although discussions are underway in this regard.

Graphically speaking, Figure 1 summarizes the changes to the global and ECA sulphur limits over time.

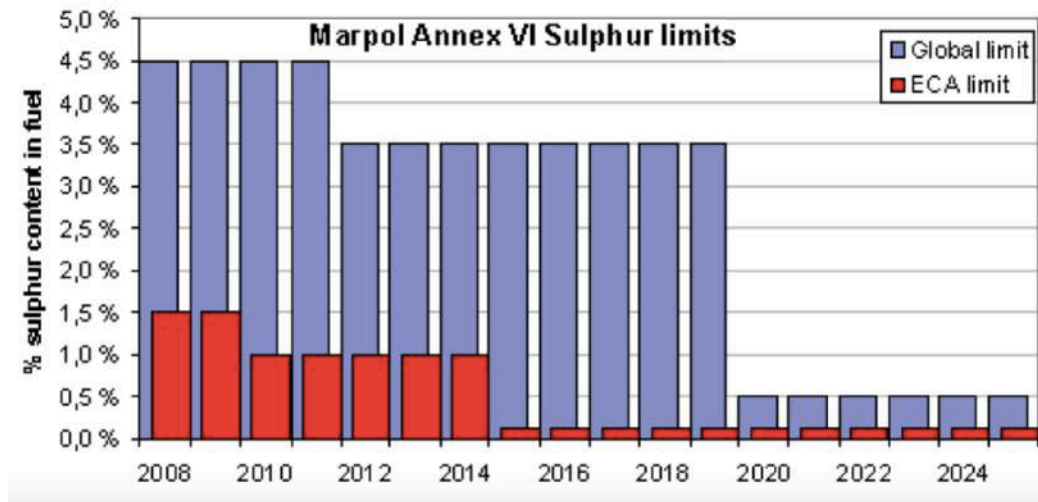


Figure 1 - Worldwide and ECA sulphur limits on marine diesel fuels. Source: IMO (2016)

As can be seen, 2015 was a significant milestone for the reduction of sulphur inside ECAs, as well as 2020 when the global limit on the emission of sulphur oxides (SOx) will see a significant reduction. In addition, 2016 saw the Tier III nitrous oxide (NOx) requirement for new build vessels come into force. Looming on the horizon is also the real possibility of the establishment of more ECAs around the world such, as previously said, the Mediterranean Sea or part thereof.

The date of 1 January 2020 was set in the regulations adopted in 2008. However, a provision was adopted, requiring IMO to review the availability of low sulphur fuel oil for use by ships, to help Member States determine whether the new lower global cap on sulphur emissions from international shipping shall come into effect on 1 January 2020 or be deferred until 1 January 2025. IMO's Marine Environment Protection Committee (MEPC 70), in October 2016, decided that the 0.50% limit shall apply from 1 January 2020.

Investigating on whether or not this date may be postponed, on the International side, we firstly find out that the date is set in the MARPOL treaty, so it can only be changed by an amendment to the MARPOL Annex VI. This would require a proposal for an amendment to be put forward by a Member State that is a Party to Annex VI, that proposal then circulated and finally adopted by MEPC. An amendment to MARPOL is required to be circulated for a minimum of six months prior to adoption and then can only enter into force a minimum of 16 months after adoption. Given that Parties to MARPOL Annex VI decided in October 2016 to implement the 2020 date, it is not anticipated that such a proposal would be forthcoming.

As far as EU waters (and the Mediterranean Sea in particular) are concerned, moreover, with the European Directive 2012/32/EU, dated 21 November 2012, which is aligned with the IMO Annex VI, there is no possibility in Europe to move the 0.5% sulphur limit on post 2020. In addition, it is currently under discussion to introduce the stringent requirements of ECAs in all EU waters.

Thus, legally, there can be no change in the 1 January 2020 implementation date, as it is too late now to amend the date and for any revised date to enter into force before 1 January 2020.

1.1.2 EU's Clean Power for Transport Package and Alternative Fuels Infrastructure (AFI) Directive

In the background of this study, globally adopted measures are as important as those that have a more limited geographical coverage. The Clean Power for Transport Package assembled by the European Commission consists of 4 main elements, all adopted by the Commission on a provisional phase on 24 January 2013:

- the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions COM(2013) 17 "Clean Power for Transport: A European alternative fuels strategy" (EC, 2013_1) laying out a comprehensive European alternative fuels strategy for the long-term substitution of oil as energy source in all modes of transport;
- a related Staff Working Document (EC, 2013_2): "Action towards a comprehensive EU framework on LNG for shipping";
- the proposal for a Directive of the European Parliament and of the Council COM(2013) 18 final "On the deployment of alternative fuels infrastructure"(EC,2013_3);
- an accompanying Impact Assessment SWD (2013) 5 final, together with its relative Summary SWD (2013) 6 final (EC, 2013_4).

This Package, which is well set within the framework of the Europe 2020 Strategy Flagship Initiatives "Resource Efficient Europe" and "Innovative Union (EC, 2010), had three goals:

1. to overcome transport dependency on oil;
2. introduce alternative fuels in order to lower greenhouse gases (GHG) emissions;
3. to kick start the market for alternative fuels in the EU.

Thus, these Commission documents propose mandatory requirements for the build-up and coverage of alternative fuels infrastructures for transport, together with common technical standards needed for their construction and, most importantly, that could ensure the interoperability of the infrastructures themselves.

Additionally, the package of measures includes also the establishment of two debate and negotiation talks. On the one hand we find a European Sustainable Shipping Forum (ESSF) that will address a sustainable waterborne transport toolbox, gathering the relevant public and industry stakeholders to provide advice and recommendations to both the Commission and Member States. On the other hand, a pool of four Expert Groups to deal with LNG as fuel, scrubbing technology, innovation and financing mechanisms.

Clean Power for Transport: a European alternative fuel strategy

The Commission's Communication COM(2013) 17 "Clean Power for Transport: a European alternative fuels strategy" sets out a comprehensive fuels strategy concerning alternative fuels and the road to its implementation covering all modes of transport, aiming at establishing a long-term policy framework to guide technological development and investments in the deployment of such fuels, also giving confidence to consumers.

It must be noticed that the strategy proposed in the Communication builds on substantial work not only with industry, but also with public authorities and civil society. In fact, evidences of such a commitment can be found in the outcomes of the European Expert Group on Future Transport Fuels (EC, 2011), the Joint Expert Group Transport & Environment, CARS 21 High Level Group, public consultation, and studies.

These efforts towards a decarbonized transport sector find their common motivation in Europe's heavy dependency on oil for its mobility. As well recalled in the Communication, oil counted in 2010 for 94% of energy consumed in transport that, with 55%, results to be the largest consumer. By simply considering then that 84% of that oil is imported, it's clear that the effect of this oil dependency on the European economy is too large to be neglected and could lead, the Commission states, to a significant deficit in the EU trade balance of around 2.5% of GDP.

In this context, the Communication COM(2013) 17 evaluates the main alternative fuel options available to substitute oil whilst contributing to reduce GHG emissions from transport. These considered alternatives are electricity, hydrogen, biofuels, Liquefied Petroleum Gas (LPG) and natural gas, in the forms of Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG).

Either technical implications and related infrastructure deployment aspects of all the options listed above will be discussed more in detail later on in this study, whereas the Communication provides general information about the nature of such alternative fuels and suggests a comprehensive list of measures to promote their market development in Europe, complementing other policies for reducing oil consumption and GHG emissions from transport. At the same time, the text of the draft Law COM(2013) 18 addresses the issue of these power sources' supply.

One of the topics which the Communication Clean Power for Transport mostly focuses on is the achievement of a fuel mix that will further reduce GHGs emissions, could entail also significant costs' abatement in the transport sector and will boost EU competitiveness avoiding market distortions.

In this regard, it is underlined that an effective strategic approach for the Union to meet the long-term needs of all transport modes must therefore build on a comprehensive mix of alternative fuels, and that all options need to be included in the strategy, not just as transition, but for the foreseeable future, without giving preference to any particular solution, thereby keeping technology neutrality.

In other words, as the stakeholders of the maritime Industry are well aware of, the Commission has stated that there is no single fuel solution for the future of EU mobility and all main alternative fuel options must be pursued, with a focus on each transport mode's peculiar needs.

Under this light, the preparatory work carried out to outline the Communication and to better direct the efforts in its implementation has brought to conclusions regarding the most suitable fuel to each transport carrier. The result is represented in Table 1 below, which takes also into account the distance factor, as some fuel options start to become efficient alternatives only once a certain distance threshold is overtaken, as well as others may be used only in the short range.

Fuel	Mode Range	Road-passenger			Road-freight			Air	Rail	Water		
		short	medium	long	short	medium	long			inland	short-sea	maritime
LPG												
Natural Gas	LNG											
	CNG											
Electricity												
Biofuels (liquid)												
Hydrogen												

Table 2 – Coverage of transport modes and travel range by the main alternative fuels. EC (2013)

Even though EU-wide availability and common technical specifications should be provided for all alternative fuels presented in the previous table, it must be considered that for vessels only a few technological options are contemplated.

In fact, exception made for biofuels, whose consumer acceptance has unfortunately been hampered by the lack of coordinated action across Member States when introducing new fuel blends, LNG is the only remaining alternative particularly suited for long-distance freight and passenger transport. This assessment has surely taken into account the impellent need for vessels to meet the new limits set by the IMO for sulphur content in marine fuels in Sulphur Emission Control Areas (SECAs) in the Baltic Sea, North Sea and English Channel, as previously recalled in this paper. Another short-term benefit deriving from the widespread use of LNG in shipping, as highlighted in the Communication, is that LNG in shipping could be economically viable, with current EU prices considerably lower than for heavy fuel oil and low sulphur marine gasoil.

Finally, it has been stressed that LNG would be an attractive alternative also on the long run for those ships operating outside SECAs, where sulphur limits will have to decrease globally from 3.5% to 0.5% as of 1st January 2020 (pending IMO's future amendments).

To further underline and legitimate the right direction taken by this study, it must be noted that, as anticipated by the Communication Clean Power for Transport and being understood the concept of technology neutrality, priorities for further action are needed to be set according especially to the stage of technological maturity of each solution.

As finally concerns Member States' commitment in the realization of the shift to alternative fuels, it is expected that these won't have only to respect a regulation on a mandatory basis. Since targets are ambitious and the time span is short, it is therefore highly desirable that each Country could count on the backing of the European Union in elaborating and implementing its national plan.

In this regard, and being aware of the current transitional phase that will be probably replaced by rapid market developments and technological improvements, it is important to recall the Communication's statement according to which the Commission will continue to support Member States, review their progress and propose any necessary changes and adjustments.

With its Communication COM(2013) 17 as first element of the Clean Power for Transport Package, the European Commission intended to catalyse the transformation of Europe's energy supply for transport, calling for a stronger consumer information, a boost of R&D and better co-ordination of public expenditures to reduce costs and improve impacts.

The Industry seemed to look at this new framework as an awaited initiative to trigger a promising market. Yet, it must be said that there are some uncertainties that affect not only Industry players.

Proposal for a Directive on the Deployment of Alternative Fuels Infrastructure

As legal and for certain aspects more binding element of the Package, the Proposal for a Directive of the European Parliament and of the Council COM(2013) 18 aimed at ensuring the build-up of alternative fuels infrastructure and the implementation of common technical specifications for this infrastructure in the Union, the lack of which is considered a major obstacle to the market introduction of alternative fuels and to consumer acceptance. Additionally, the development of such infrastructure is firmly required to be achieved on a harmonized basis across the whole European Union network, in order to ensure interoperability.

Thus, the draft Directive recalled the European Commission's White Paper (EC, 2011) goals in terms of achieving the take-up of the alternative fuel vehicles' and vessels' market announced in it, but with a special care to the current economic climate. As a result, that initiative was more likely to be in line with stakeholders' expectations, since it provides a political market trigger that sets out to create incentives and send signals for investments.

The main alternative fuel options considered by the Directive were those anticipated by the strategy proposed with the Communication COM(2017). On the other hand, in the Impact Assessment SWD(2013) 5 Accompanying the Proposal for a Directive, has been highlighted that market failure in the provision of recharging/refuelling infrastructure affects particularly the deployment of three alternative transport fuels: electricity, hydrogen, and natural gas (LNG and CNG), whereas the other main alternatives to oil, that is to say biofuels and LPG, were less concerned. Thus, stronger initiatives are needed to be put in place in order to change this asset. In this sense, to better stress the right path to be followed under those initiatives, the draft Directive pointed out that it would be potentially inefficient to make investments in infrastructure if the relevant technology is not ready.

For this reason, it is important to recall that, Commission said in its Staff Working Document, early a decade of small scale LNG driven ships experience has proven the reliability of the technology.

The final Directive, as adopted by the European Parliament and the Council on 29 September 2014 following the inter-institutional negotiations has the following shortfalls:

- Requires Member States to develop national policy frameworks for the market development of alternative fuels and their infrastructure;
- Foresees the use of common technical specifications for recharging and refuelling stations;
- Paves the way for setting up appropriate consumer information on alternative fuels, including a clear and sound price comparison methodology.

The required coverage and the timings by which this coverage must be put in place is as follows:

	Coverage	Timings
Electricity in urban/suburban and other densely populated areas	Appropriate number of publically accessible points	by end 2020
CNG in urban/suburban and other densely populated areas	Appropriate number of points	by end 2020
CNG along the TEN-T core network	Appropriate number of points	by end 2025
Electricity at shore-side	Ports of the TEN-T core network and other ports	by end 2025
Hydrogen in the Member States who choose to develop it	Appropriate number of points	by end 2025
LNG at maritime ports	Ports of the TEN-T core network	by end 2025
LNG at inland ports	Ports of the TEN-T core network	by end 2030
LNG for heavy-duty vehicles	Appropriate number of points along the TEN-T core network	by end 2025

Table 3 – Coverage of alternative fuels infrastructure required by DAFI.

The Member States had two years to submit their national policy frameworks.

Besides the NPF, the Directive also regulates common EU-wide standards for equipment needed and user information. These latter two aspects are governed by the general transposition provisions of the Directive, which aims at facilitating a functional internal market for alternative fuel vehicles and technology, and infrastructure build-up. The targets and objectives of the NPF can have an impact on:

- creating a minimum level of recharging and refuelling infrastructure across the EU including cross-border continuity and enabling market uptake of alternative fuel transport systems,
- the achievement of EU climate and energy objectives,
- improvement of air quality,
- strengthening the EU's competitiveness and jobs.

The figure below schematically describes how the estimates, targets and measures for the alternative fuel vehicles and alternative fuels infrastructure described in the NPFs interact and how these combined impact EU wide goals.

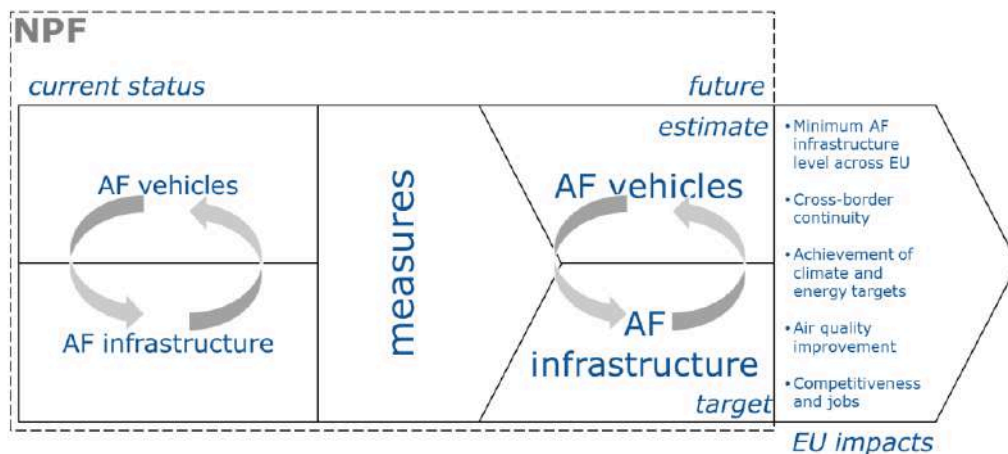


Figure 2 - Interaction of various aspects covered in the NPF and resulting impacts. Source: European Commission (2017)

As far as the state of play for NPFs implementation in the EC's Staff Working Document (EC, 2017) is concerned, it is noted that the completeness, coherence and ambition of the NPFs vary greatly. By the end of 2017, only 8 out of 25 NPFs fully met the NPF requirements. Two Member States have not submitted their NPF until the last year.

The NPFs are not coherent from an EU perspective in terms of the priorities they set and how ambitious they are with regard to different alternative fuels. Member States' ambition to change the current state of affairs varies a lot, both in terms of projected deployment of vehicles and vessels running on alternative energy and the related infrastructure. Most importantly, only a few NPFs set clear and sufficient targets and objectives and suggest support measures. One NPF contains no targets.

There are LNG targets for heavy-duty road vehicles in 19 NPFs, but target-setting and planning of action is not always appropriate and will not result in the necessary coverage of the core TEN-T road network. Only 5 NPFs set estimates for future LNG heavy-duty vehicles deployment.

A few NPFs set ambitious targets for future LNG infrastructure deployment in maritime and inland ports. However, several of these do not address LNG refuelling point needs in maritime ports by 2025 and

inland ports by 2030. A number of ports in the TEN-T core network risk being left without any solution for LNG refuelling.

1.1.3 Other relevant international and EU regulations

Together with MARPOL convention, there are a number of IMO regulations that are relevant to the subject of this study.

Firstly, being a gaseous fuel of flashpoint lower than 60°C (actually -175°C), LNG could not be considered as fuel within SOLAS frame⁴. Due to that reason, addressing the particular aspects concerning safe use of LNG as fuel, building from the experience of the IGC Code and from the application of Interim Guidelines (IMO, 2009) the IGF Code was developed. Containing what is today the best collection of provisions for the design, construction and operation of LNG fuelled ships the IGF Code entered into force on 1st January 2017 and is the central focus of this section. Its functional requirements are further outlined in this section and a parallel is established with the whole LNG bunkering interface, making the relation that similar functional requirements should be applicable throughout the entire LNG bunkering scenario.

On its own, the IGF Code represents a highly relevant instrument, defining the safety requirements for the construction and operation of LNG fuelled ships and, at the same time, defining the level of ambition in terms of safety, relevant safeguards, control and associated procedures.

From the IGF Code the following Chapters are of particular relevance in the context of LNG Bunkering:

- Section 3.2 - Functional Requirements
- Chapter 8 – Bunkering: outline of functional requirements for bunkering equipment (ship-side) with requirements to the Bunkering Station and manifold onboard the LNG fuelled ship)
- Section 18.4 – Regulations for Bunkering Operations: description of operational procedures to be followed for LNG bunkering, with the description of the particular responsibilities for the PICs and operational aspects related to communications, control and safety systems and verification of conditions for bunkering)
- Section 15.4 – Regulations for bunkering and liquefied gas fuel tank monitoring: set of requirements specific for LNG tank filling monitoring, especially relevant during bunkering, both for overfills mitigation and for LNG vapour management.

⁴ The use of fuels with flashpoint lower than 60°C is not permitted as per SOLAS 1989/1990 Amend / Chapter II-2 / Reg. 15

- Section 15.5 – Regulations for bunkering control: LNG bunkering control aspects, including requirements for LNG bunkering control location.

The IGF Code requirements and good practice grounding on it, may be expanded to the LNG Bunkering Interface and Shore-Side.

EU Sulphur Directive

In the EU, SO_x emissions from ships are regulated by Directive 2016/802/EC, known as the 'Sulphur Directive'. The recent codification includes not only the limitation on the sulphur content of marine fuels but also of land-based oil fuels, establishing limits on the maximum sulphur content of gas oils and heavy fuel oil. The Directive also contains some additional fuel-specific requirements for ships calling at EU ports, obligations related to the use of fuels covered by the Directive and the placing on the market of certain fuels (e.g. marine gas oils). The Directive had been previously amended by Directive 2012/33/EU, now repealed, in order to further adapt the European Union's legislation to developments at international level under MARPOL Annex VI as already previously noted. Furthermore, passenger ships operating on regular services to or from any EU port shall not use marine fuels if their sulphur content exceeds 1.50 % in sea areas outside the SECAs.

The relevance of the Sulphur Directive in the context of LNG as fuel comes in the terms of Article 8, according to which Member States shall allow the use of emission abatement methods (EAMs) by ships of all flags in their ports, territorial seas, exclusive economic zones and pollution control zones, as an alternative to using marine fuels. Being an alternative fuel, LNG is eligible to be considered an Emission Abatement Method, and its use should be allowed in ships of all flags in ports, territorial seas and economic exclusive zones of the EU. Ships using EAMs in these areas shall continuously achieve reductions of sulphur dioxide emissions that are at least equivalent to the reductions that would be achieved by using marine fuels.

EU Port Regulation

Regulation (EU) 2017/352 Of The European Parliament And Of The Council of 15 February 2017 establishes a framework for the provision of port services, and common rules on financial transparency and on port service and port infrastructure charges, being applicable to all maritime ports of the trans-European transport network, as listed in Annex II to Regulation (EU) No 1315/2013 (EU TEN-T core ports).

Regulation (EU) 2017/352 includes a large number of concepts which are relevant in the context of this Guidance. The concept of “bunkering”, “competent authority” and “managing body of the port” are all related directly to the present Guidance, and their definitions are adopted in this document (see section 1.4) with the intention to use this regulation as an immediate legal reference to good practice guidance included in this document. LNG bunkering is directly within the scope and applicability of this Regulation (Chapter II, Article 1). The aim of Regulation (EU) 2017/352 is to ‘level the playing field’ in the sector, and create a climate more conducive to efficient public and private investments. The Regulation defines the conditions under which the freedom to provide port services apply, for instance the type of minimum requirements that can be imposed for safety or environmental purposes, the circumstances in which the number of operators can be limited and the procedure to select the operators in such cases. It introduces common rules on the transparency of public funding and of charging for the use of port infrastructure and port services, allowing the differentiation of port infrastructure charges in order to promote among others high environmental performance and energy or carbon efficiency of transport operations. It places particular emphasis on the consultation of port users and other stakeholders. It requires each Member State to have in place a clear mechanism to handle complaints and disputes between port stakeholders. Finally it requires all port service providers to ensure adequate training to employees.

Regulation (EU) 2017/352 was published on the 15 February 2017, having entered into force in all EU MS twenty days after that and being applicable from 24 March 2019.

Seveso III Directive

Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC includes obligations on the operator, in particular measures to prevent major accidents and the requirement to communicate information on potential major-accidents with dangerous substances on its establishments. Transport outside establishments and directly related intermediate temporary storage of dangerous substances (including loading and unloading) are specifically excluded from this directive by Article 2(2) (c). LNG is listed as a named dangerous substance in entry 18 of Annex I Part 2 to the Directive. This Directive is applicable to all⁵ LNG installations, except offshore exploration, underground offshore gas

⁵ The Seveso III Directive does not differentiate between onshore and offshore. To this end, as an example, a ship or another floating unit could be subject to this Directive provided that it falls out of the temporary storage situation. In addition, where a barge is used as a permanent storage unit. This can actually be a risk reduction measure to keep greater distance from the onshore part of the establishment. Such situations fall under the Seveso III Directive. Only the offshore exploration of gas and oil as such is excluded.

storage. All establishments which hold at least 50 tonnes⁶ of LNG (less if other dangerous substances are also present) fall under the scope of the Directive and, amongst others, need to establish a major accident prevention policy. In addition, operators of upper tier establishments holding more than 200 tonnes of LNG (equivalent to approximately 440 m³) need to establish, amongst others, a safety report. This safety report must include identification and assessment of major hazards and necessary measures to prevent major accidents. Other requirements include a safety management system and emergency plan. Loading and unloading of dangerous goods and the related safety aspects are in principle governed by legislation on transport.

Specific aspect on the applicability of the Seveso III Directive requirements	EMSA suggested approach
<p>A. Temporary Storage</p> <p>Despite being clear regarding the non applicability of Seveso III Directive to LNG transport, there are cases where temporary situations will require additional judgement. Some examples are presented below:</p> <ol style="list-style-type: none"> 1. LNG truck trailer left temporarily in LNG Bunkering location 	<p>These examples could meet the conditions for 'intermediate temporary storage'. Although, there is no common definition of 'intermediate temporary storage', the Seveso Expert Group has concluded that this refers to necessary intermediate storage in the transport chain. Whilst the unloading of trucks/containers does not define the location as a Seveso establishment there may be implications for the location where the loading takes place⁷. If it takes place within a site which is already classified as a Seveso establishment, the amount of dangerous substances involved would have to be considered by the operator of the establishment,</p>

⁶ Also establishments with less than 50 tonnes can be covered if other dangerous substances are present. This could be very relevant in harbours where other fuels are present. Under the Seveso III Directive different dangerous substances are summed up. This is an important point to take into account when assessing on the applicability of the Seveso Directive requirements to a given small scale/bunkering project.

⁷ A similar understanding can be found in USCG CG-OES Policy Letter 02-14, where it is considered in enclosure (1), point 1) a) that LNG tank trucks and railcars are not considered waterfront facilities handling LNG. However, when trucks or railcars are used as a means for transferring LNG to a marine vessel, the location where the transfer occurs may so be considered.



2. Bunker barge, non-propelled, left alongside a ship, or moored alongside a pier.



e.g. whether or not the storage is temporary. The exclusion in Article 2(2) (c) only applies to temporary storage 'outside the establishment'. In this case the relevant Seveso establishment would have to consider the activities within or nearby its establishment as a potential risk factor and where necessary adapt its risk management measures accordingly. On the other hand, if the loading takes place within a site which is not (yet) classified as a Seveso site (but where certain amounts of dangerous substances are present, though below the thresholds), then it will be important to assess the temporary character of the loading. In the light hereof, it would play a role how often and how long the fuelling activity takes place at the location. If there is a frequent presence of at least 50 tonnes of LNG over a longer period of time it could be argued that there was a de-facto (semi-) permanent presence of a certain amount of a dangerous substance (i.e. LNG) at a certain location, even if the actual truck or mobile container changes. In which case the operator responsible for the location may have to check with the competent authorities whether the location might have to be considered a Seveso establishment or the de-facto (semi-)permanent presence of the LNG may have to be added to the inventory of dangerous substances at the location. However, LNG (or any other fuel) that is actually used to fuel vehicles (i.e. contained in the corresponding fuel tank of the vehicle) is not taken into account. Following the above, the applicability of Seveso III Directive requirements to intermediate storage situations, as the ones presented in 1, 2 and 3 should be subject to case-by-case assessment by the BFO and PAA, in consultation with the competent authorities, which should in the best interest of safety have the following


<p>3. ISO framed LNG container</p> 	<p>elements into consideration:</p> <p>Quantities of LNG actually or anticipated to be present in intermediate storage • Whether or not the intermediate storage is directly related to transport outside Seveso establishments • Duration and frequency of the intermediate storage • Other risk factors at the location or in its proximity such as intermediate storage of other hazardous substances. The particular case of the ISO containers may be further divided in 3 (three) different situations: 1) LNG ISO container at the end of the transport chain; 2) LNG ISO unit cargo in-between the transport chain; 3) LNG fuel units for ISO bunkering of LNG fuelled ship. Whenever considered as part of an “LNG Virtual Pipeline” concept, these LNG ISO containers can be potentially waiting in the port area for embarkation on-board a container vessel to a different destination. For any of the cases presented above it is important to identify the end of the actual transport chain and, again, to address intermediate storage considering the elements listed above.</p>
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Table 4 – Seveso III Directive– applicability to LNG bunkering. Elaboration on EMSA (2018)

All the above situations, explored in terms of Seveso III Directive requirements applicability, may be subject to case-by-case assessments. Notwithstanding this, the following conclusions may be taken in accordance to the definition of a good practice approach in the permitting of LNG bunkering facilities:

- Seveso III does not apply to mobile units undertaking transport of LNG outside Seveso establishments. The bunkering operation in itself, being part of the logistic chain, is also part of the LNG distribution. Article 2(2)(c), therefore, typically applies to LNG trucks and LNG bunkering vessels or barges provided that it is directly linked to the transport in which case it would be unloading.

- The location where bunkering takes place, however, can be considered as a specific location where hazardous substances are handled, in this case LNG, and therefore be subject to consideration for application of Seveso.
- Competent Authorities for Seveso III Directive requirements, at national level, should engage periodically with PAAs to assess specific situations that may result from continuously developing LNG bunkering technology.
- LNG bunkering, in otherwise-Seveso installations (i.e. installations already classified as Seveso) should be carefully considered, e.g. in light of possible domino effects. Safety Distances should take pre-existing hazardous substances into account.

EU Environmental Impact Directive

Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment, as amended by Directive 2014/52/EU, defines the Environmental Impact Assessment (EIA) process which ensures that projects likely to have significant effects on the environment are made subject to an assessment, prior to their authorization. Consultation with the public is a key feature of EIA procedure. The EIA Directive applies to a wide range of public and private projects, which are defined in Annexes I and II. Annex II lists so called “Energy Industry” projects and more specifically storage of gas. For projects listed in Annex II, the national authorities have to decide whether an EIA is needed (by a so-called “screening procedure”). Although the EIA Directive specifies no specific thresholds or criteria for ‘storage of gas’ (LNG) installations, during the screening procedure the national authorities must take into account the criteria laid down in Annex III. The EIA Directive also specifies the requirements on participation of environmental authorities, local and regional authorities, affected Member States as well as the public in the process. Together with Seveso III, the EIA Directive can be a relevant instrument for LNG bunkering projects, especially with regards to Permitting processes. As LNG bunkering projects fall under Annex II of the EIA Directive and Member States may have introduced different thresholds or criteria for this type of projects, it is important to verify the applicable national legislation. The Directive, as such, aims to set the framework for EIA and, national legislation to provide for the technical measures. As indicated above, it is the responsibility of each Member State to identify the thresholds and/or criteria for LNG storage capacity above which the provisions of the Directive apply, or they can apply case-by-case examination to determine if Annex II projects shall be subject to EIA. Whether an LNG project, with local small-scale storage, would be subject to an EIA should be a result of a determination in accordance with national legislation transposing Art. 4(2)-(6)

of the EIA Directive. In section 4.6.5 a good practice procedure is included to address the screening and assessment of LNG bunkering projects, in the wider context of permitting process.

ADR – European agreement concerning the International Carriage of Dangerous Goods by Road

The transport of hazardous goods by road is covered in the European Agreement concerning the International Carriage of Dangerous Goods by Road, commonly known as ADR (*'Accord européen relatif au transport international des marchandises dangereuses'*) from the Economic Commission for Europe (UNECE or ECE). The ADR is translated and included in the national legislation of the applicable countries. The Agreement itself is short and simple. The key article is the second, which describes that, excluding some excessively dangerous goods, other dangerous goods may be transferred internationally in road vehicles subject to compliance with the conditions laid down in Annexes A (packaging and labelling) and B (construction, equipment and operation of the vehicle carrying the goods in question).

Trucks that transport LNG are subjected to Annex A with respect to labelling of hazardous materials and to Annex B when it comes to construction of the cargo tank. Trucks that are using LNG as fuel are subjected to Annex B for the construction of the fuel tank. A new version of the ADR has entered into force the 1st of January 2017. No modifications impacting LNG transport via trucks have been made.

Port-related Regulatory framework specific for LNG bunkering and local provisions

The LNG bunkering operations which the Port of La Spezia, object of this study, is expected to be experiencing in the coming years, will be likely carried out following the prescriptions of the Guidance on LNG Bunkering to Port Authorities and Administrations recently developed by the European Maritime Safety Agency (EMSA, 2018). In such document, different regulatory instruments relevant to LNG Bunkering are listed.

The Regulatory Framework for LNG Bunkering, on the shore-ship or ship-to-ship interface, is composed of high level regulatory instruments, standards and guidelines and industry good practice references. Not only the hierarchy of the references is different but they exist in two separate regulatory frames that often result in gaps or overlaps in the bunkering interface. The receiving ship, the bunker barge, or bunker vessel, the LNG truck, the LNG terminal and possible small scale storage.

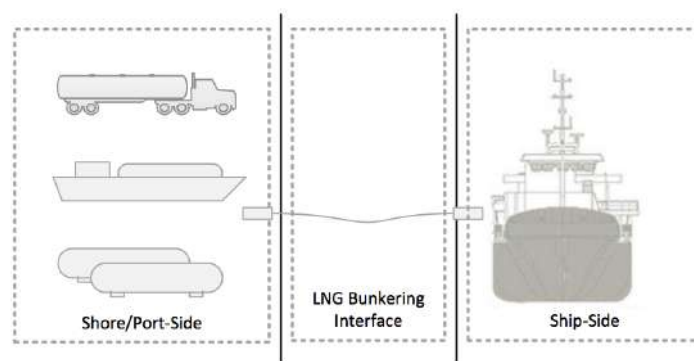


Figure 3 - LNG Bunkering – Ship-Shore interface

According to the EMSA study, the international (global or regional) regulatory framework is composed of 4 essential levels to which a fifth level can be added, accounting for Port regulations that are able to, locally, shape the specific regulatory environment for LNG Bunkering.

<u>High Level</u>	<ul style="list-style-type: none"> •IGF Code/ SOLAS/ STCW •MARPOL - MARPOL Annex VI •EU Sulphur Directive •Alternative Fuel Infrastructure Directive 	High level instruments are relevant in the definition of the main drivers for adoption of LNG as an alternative fuel . Mostly environmental related, globally/regionally binding.
<u>Standards</u>	<ul style="list-style-type: none"> •ISO Technical Specifications and International Standards •EN Standards •Equipment Standardization 	Technical Standards are relevant for LNG bunkering operations and equipment, including small scale LNG storage. They are binding through reference to higher level regulatory instruments.
<u>Class Rules</u>	<ul style="list-style-type: none"> •IACS URs/Recs •Class Rules for Construction •Guidance Notes •Guidelines 	Class Rules are relevant instruments for Classification Societies to ensure safety, quality and compliance in the application of international regulations, following a common technical interpretation of different provisions.
<u>Industry Guidance</u>	<ul style="list-style-type: none"> •SGMF Guidelines •Industry Guidance •Guidance Notes •LNG Bunkering Check Lists 	Industry references are fundamental in definition of the best practices in LNG bunkering, both on equipment, safety, operations and outline of responsibilities. Non-binding set of best practices.
<u>Port Local Regulations/ Byelaws</u>	Port specific regulations Ports can set rules by themselves, addressing specific operational aspects and their specific context. Port Byelaws often reflect the nature of each port authority management principle. They are of local and limited application, reflecting	

Figure 4 – Levels of the International regulatory framework on LNG bunkering. Source: EMSA (2018).

The High Level includes the instruments that have been dealt with in section 1 of this study, whereas for the standards, the class rules and industry guidance, reference to the EMSA Report is to be made for further deepening the subject.

Yet, being Port Regulations the best vehicle to integrate all the hierarchy for the mentioned regulatory instruments, a focus on those is here provided.

On one hand including the higher level instruments and, on the other, bringing the reference to Technical and International Standards, Port Regulations are, in fact, important in the adequate definition of the complete legal and administrative framework for LNG bunkering.

A number of recommendations are given by EMSA when it comes to shaping Port Regulations in EU Ports, of which the following selection is relevant to highlight the relationship between local and wider-scoped instruments, b):

- Ports should set rules to control LNG Bunkering, and small scale LNG installations, by themselves, in the context and frame of their jurisdiction and meeting closely the relevant national and international applicable legislation. Ports should, in this respect, note that the alignment of port regulations/byelaws with the full hierarchy of legal/reference instruments is fundamental to the harmonized and safe development of LNG Bunkering.
- When developing Port Regulations specifically for LNG bunkering PAAs should align these with all the relevant regulatory references affecting the use of LNG as an alternative fuel in shipping, handling of hazardous substances within the port area, transport of hazardous substances by road and waterways.
- The applicable regulatory frame, for each individual Port, will be the sum of the different instrument types. Ports should develop their regulations in strict observation of the available instruments, allowing in addition for additional justifiable provisions in order to improve safety in LNG bunkering operations (e.g. in the case of lessons learnt from casualties, incidents or near misses).
- Whenever Port Regulations include requirements of higher stringency than those within national regulations, or technical measures understood to be different of those prescribed in International Standards, a substantiated justification should be included, preferably with the inclusion of possible alternative means of compliance. Whenever these alternative means are not expressed, a case-by-case analysis may be a possibility to be considered, allowing for the demonstration of equivalency.

- Port Regulations should be aligned with the National Policy Framework defined at National Level⁴²⁸ in all aspects related to LNG as Fuel. As part of the wider value chain for this Alternative Fuel, Ports represent important elements in the transfer of both LNG as fuel and LNG as cargo. They should therefore be aligned with the main national policy vectors.
- Notwithstanding the importance of aligning LNG bunkering developments and infrastructure with the National Policy Frameworks, PAAs should also consider that LNG as fuel is a cross-border development. Apart from aligning with national wide policy it is also recommended that PAAs adopt dialogue and cooperation channels to allow shared development of LNG bunkering regulations aiming towards a harmonized approach to control measures.
- Whenever evaluating or facilitating in favour of prospective LNG bunkering projects, PAAs are advised to consult closely with the national competent authority for the implementation of Directive 2014/94 on the deployment of an alternative fuel infrastructure. National Policy Frameworks should be able to provide the necessary environment for the consideration of LNG bunkering facilities, in the context of availability of LNG as fuel in maritime core-ports.
- In the case of a National Policy Framework containing specific measures of any nature that may determine or influence the permitting process for a give prospective LNG bunkering facility project, PAAs should exercise a facilitating role and assist, wherever possible and relevant, with information to operators.

Those listed hereinafter, instead, are relevant as they recall the specificities of the operations which are also addressed by the present study:

Port Regulations should define clearly the Scope in terms of the different LNG bunkering modes. Different modes for LNG transfer will inherently represent different operational considerations and instrumental/technical/legal references. Existing industry guidelines, or best practice documents, usually privilege one, or some, of the possible LNG bunkering modes.

PAAs should have the LNG Industry Bunkering Guidelines⁹ as the relevant documents where industry best practice is reflected, resulting from a significant number of stakeholders in the Industry with experience in LNG. Functional requirements for LNG bunkering equipment, where listed, are also the reflection of current experience and good practice, not only in terms of the LNG Transfer System equipment but also regarding

⁸ National Policy Frameworks defined as per Article 3 of Directive 2014/94

⁹ Listed in Section 4.4 of EMSA guidelines

operational aspects. PAAs should nevertheless be aware that these documents are not mandatory in nature and should, in the context of a legal framework, be incorporated as references into national or port regulations.

European Union actions have been timely carried out to comply with IMO's requirements with respect to air pollution from ships since 1999, when Directive 1999/32/EC served as the EU legal instrument to incorporate the sulphur provisions of the MARPOL Annex VI.

The original Directive has been then replaced by Directive 2005/33/EC, that extended the scope of the previous one not only adapting to new IMO's amendments, but also introducing a 0.1% maximum sulphur requirement for fuels used by ships at berth in EU ports from 1 January 2010 onwards.

Finally, that Directive has then been recently amended by Directive 2012/33/EU, in order to further adapt the European Union's legislation to the recent developments under MARPOL Annex VI, particularly with respect to SECAs requirements, whereas, on the contrary, there is currently no binding EU legislation on NOx emissions reductions from ships.

It is thus clear that multilateralism and broad based cooperation are continuing to be central for EU's climate policy that moves forward supporting ambitious global action to address climate change. And precisely to be consistent with this international narrative, the EU is outlining a new scenario to facilitate its own transition to a low carbon economy, even with initiatives put in place on a unilateral basis. In fact, it is well known that one of the lately hottest and controversial topic regarding the maritime transport sector is the introduction of a form of MBM (Market-based Measure) to curb ships' emissions, introducing them in a global regulatory system. Potential measures that, despite having been in-depth considered by every single MEPC since MEPC 56 (July 2006), have not yet found an agreement at IMO level even during latest MEPC sessions.

In this field, it must be recalled that the European Union have already taken unilateral actions within the aviation sector with Directive 2008/101/EC amending Directive 2003/87/EC so as to include aviation activities in the EU-ETS (European Union Emission Trading Scheme) and now, also regarding the shipping sector, the European Commission is moving forward in this sense, in order to meet environmental targets and reach the goals of its transport policies. Under this light, in fact, the Communication COM(2013) 479 final from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions of the 28th June 2013 represents the first step to integrating

maritime transport emissions in the EU's greenhouse gas reduction policies, while at the same time maintaining a global level playing field for the Industry.

1.2 Drivers, enablers and challenges of LNG introduction in waterborne transport

As already previously identified within the Small Scale LNG Triennium Work Report (IGU, 2015) produced by the Program Committee D3 of the International Gas Union, a number of factors are determinant in outlining the reality of Small Scale LNG worldwide in its complex.

As far as the drivers and barriers specifically identified for the demand and the supply of LNG as a bunkering fuel for waterborne transport are concerned, the Study on the Completion of an EU Framework on LNG-fuelled Ships and its Relevant Fuel Provision Infrastructure (EC, 2015), developed by CE Delft by mandate of the EC DG MOVE, better analyzes the theme, with a major focus on EU ports.

1.2.1 Key Drivers

The key observed drivers for SSLNG developments are:

- Economics: energy cost advantage of LNG over alternative energy sources for end-users, including gas in the absence of pipeline infrastructure. An example is given in Figure 4 for the use of LNG as transport fuel compared to diesel.
- Environmental: small scale LNG can bring attractive environmental benefits both to the gas production (preventing flaring) as well as end-customer use (LNG for transport / power & heating generation), compared to alternative fossil fuels. This includes CO₂, SO_x, NO_x, particles and noise emissions.
- Governmental decisions to increase the level of energy independence for a country or region by developing an alternative energy supply.

Most business opportunities have multiple drivers. SSLNG production has been traditionally considered an important business in North America, Asia (China, Japan) and Europe (specifically in the Scandinavian region). The relevance of the drivers for small scale LNG varies per region, see Figure 5. For example in Scandinavia, the main driver is environmental, where the main drivers in the US are mostly economic and China mostly both economic and environmental. Geo-political drivers for national governments are entering the SSLNG space recently as well, mainly for customers to become more independent of pipeline gas suppliers.



Figure 5 - Regional main drivers for SSLNG. Source: Shell (edited version)

Regarding the main economic drivers on the LNG demand side, in this case the attention is more focussed on the difference between the LNG price and the price for the other bunker fuel types as well as future environmental policy (e.g. more ECAs, CO₂ regulation for international shipping), which are all expected to play a crucial role in the uptake of LNG-fuelled ships. It has been noticed that the price difference between LNG bunker fuel and HFO/MGO/MDO mainly determines the fuel expenditure difference between an LNG-fuelled ship and a HFO/MGO/MDO fuelled ship. Since fuel expenditure savings have to be sufficiently high to compensate for the higher investment costs of an LNG-fuelled ship, the relative LNG bunker price is a very crucial factor on the demand side of the LNG bunker fuel market. The bunker prices of HFO/MGO/MDO have historically developed in line with the crude oil price and since mid-2014, the bunker prices have been falling along with the crude oil price. If EU LNG import prices are not linked to the crude oil price, then the relative price of LNG bunker fuel will rise, discouraging the uptake of LNG-fuelled ships.

1.2.2 Main Enablers

The key enablers applicable to SS bunkering can be summarized as follows:

- **Technology:** the development and maturation of small scale LNG technology is seen as the key enabler. For example, more efficient and cost-effective small scale liquefaction processes are being developed, while for LNG as transport fuel, gas engine technology is rapidly developing.
- **Financing:** the availability of relatively “cheap” money can generate regional attractiveness to invest in SSLNG projects and attract new players to the market. The SSLNG projects require lower investments as they are smaller than conventional projects. Even with these lower investments, most companies need a certain level of commitments from its customers.
- **Fiscal regime and subsidies:** in some cases, small LNG production projects can help to develop natural gas consumption both as a temporarily supply or to feed remote areas that are not connected to the main transportation grids. Therefore the (local) authorities can provide attractive fiscal packages that support LNG development. Various European countries have proposed building small-scale import terminals, supported by EU subsidies that could be as large as 10-20% of the terminal development cost. Alternatively, more polluting fuels may be subject to higher taxation.
- **Stimulating policy and regulations:** enforcement of environmental benefits is typically imposed by government interventions through policies or regulations (ECA zones).

1.2.3 *Main associated challenges*

Below the key challenges, also underlined by the Small Scale LNG report (IGU, 2015) are given.

- **Cost:** the main challenge of the SSLNG industry relates to the costs due to the lack of economies of scale and expensive materials (cryogenic).
- **Fit-for-purpose engineering:** SSLNG has attracted big and smaller players to the market. For the larger players, an observed challenge is to develop cost-effectively and fit-for-purpose technological solutions, while not compromising company and safety standards.
- **Safety:** for new players entering the SSLNG market, maintaining safe and reliable operation can be a challenge when lacking LNG experience. Additionally, the SSLNG network involves many parties and smaller parcel sizes, requiring a framework of standards and guidelines to maintain the current safety level in the industry.
- **Availability of supply and demand:** the growth of the SSLNG business is linked to deliverability and sustainable demand for LNG. This creates a potential stalemate where consumers wish for security of supply before committing to LNG, while potential suppliers need to secure a market to justify the investment. The unlocking of such a dilemma is being addressed in different ways in different parts

of the world. This challenge will disappear gradually as the market develops further and SSLNG becomes a more widely traded commodity.

- Full supply chain development: several SSLNG opportunities become only feasible with a complete supply chain development, from source (gas field, pipe-line), all the way to end- customers. Many parties have looked at elements but there are very few examples of parties that have succeeded on creating a full small scale supply chain. The challenge here is to operate and design all elements of such a supply chain effectively and competitively.
- Lack of (consistent) and change of policy and regulations: mainly for less developed markets the absence of policies should be considered when developing a new SSLNG project in a country without previous experience in LNG, in such a case, the developers should refer to and use the available international set of standards and guidelines

Additionally, as well identified by Deloitte (2016) and recalled here being useful for the purpose of this research, another challenge is storage, as boil-off and operating costs make storing LNG rather impractical and expensive.

Ultimately, it is worth mentioning that the challenge of widespread transport of LNG comes down to volume, since natural gas requires on the order of 1,000 times the space as crude oil on an energy equivalent basis.

Time and experience is expected to offset these challenges as this SSLNG industry becomes more mature.

Regulatory uncertainty regarding environmental regulation and the uncertainty regarding the future prices of the different bunker fuels makes it difficult for a ship owner to predict whether an investment into an LNG-fuelled ship will be profitable.

In addition, there are other factors adding to this uncertainty. Firstly and most importantly, there is the uncertainty about the future availability of bunkering infrastructure in European ports, secondly, there is the uncertainty whether sufficient supply of LNG can be guaranteed for the European market, thirdly, there is uncertainty about technical standards, and fourthly there is the regulatory uncertainty regarding safety standards.

The uncertainty about standards is likely to be reduced in the coming years. The European Commission has requested the European standardisation organisations to develop uniform technical standards and the International Code of Safety for Ships using Gases or other Low flashpoint Fuels (IGF Code) has been adopted by the IMO Maritime Safety Committee in June 2015, but a clear regulatory framework for

bunkering LNG as fuel for ships including relevant regulations of the LNG supply chain is not available yet, except for the previously cited EMSA guidance. Existing standards and guidelines can be used to fill this gap, but rules may then differ between ports/countries, leading for example to different risk assessments and approval procedures. The LNG stakeholders and ports have an incentive to harmonise the procedures. This is why there are initiatives like the harmonized bunkering checklists for LNG operations in port as developed by the IAPH's WPCI LNG working group, but since these initiatives and guidelines from the industry might be overruled by regulation in the future, some degree of uncertainty remains. In the following table, the possible impacts on the demand side of the LNG bunker fuel market due to the uncertainty regarding standards and bunkering rules/regulations are listed. Please see the Lot 1 report of this study (DNV GL; PWC, not yet published) for further details on technical and safety standards regarding the LNG bunker fuel supply chain.

Type of uncertainty	Impact on demand side
No/insufficient safety standards	<ul style="list-style-type: none"> • Probability that accident happens is higher, discouraging investment; • Costly risk assessment of LNG systems and components.
No/insufficient technical standards, leading to technical incompatibilities	<ul style="list-style-type: none"> • Ship might not be able to bunker in certain ports; • Investment in LNG ships may be reduced if bunkering is constrained to a limited set of ports
Introduction of standards that have not been anticipated	<ul style="list-style-type: none"> • Additional extra measures may have to be taken leading to unexpected costs and/or earlier investments may become obsolete
Different bunkering rules/regulations between ports	<ul style="list-style-type: none"> • Costly for ship operators to keep track of and fulfil different rules/regulations; • Ship might not be allowed to bunker in certain ports.

Table 5 – Possible impacts on the demand side of the LNG bunker fuel market due to uncertainty w.r.t. standards.

This work grounds on the assumption that **a key enabler in the evolution of LNG as fuel is the availability of Small-Scale LNG (SSLNG)**. Actually, the global SSLNG installed production capacity is of 20 Mtpa. Most of the growth is in China, where efforts are in place to get clean fuels to fight air pollution stimulated by the availability of gas and the price differential between natural gas and diesel oil.

1.3 LNG main features and supply chain

1.3.1 Characteristics of LNG

LNG is a mixture of hydrocarbons, predominately methane (80 – 95%). Other significant components include other alkanes –ethane, propane and butane. Nitrogen may also be present at levels up to 1%. All the more complex hydrocarbons, along with carbon dioxide and sulphur compounds, are removed to trace level. It is created by cooling natural gas to -162°C (liquefaction process): During this process, the natural gas, which is primarily methane, is cooled below its boiling point, whereby certain concentrations of hydrocarbons, water, carbon dioxide, oxygen, and some sulphur compounds, are either reduced or removed.

The reduction in the volume of NG by 600 times, when liquefied, allows its transport as LNG, as it takes significantly less space than natural gas (600 cubic meters of Natural Gas = 1 Cubic meter of LNG).

Odourless, colourless, non-toxic non-corrosive liquid. If spilled, it will disappear quickly without corroding the surface. Has cryogenic properties. If spilled on the ground, it will become colder. If mixed with water, it will not be absorbed to the water, nor will it pollute it.

Natural gas burns cleaner than other fossil fuels. The primary products of the NG flame are heat carbon dioxide and water. It has a high ignition temperature of 628°C (Propane= 493°C, Butane= 405°C, Kerosene= 295°C, Gasoline=246°C) and burns like a candle than a blaze. This makes LNG more difficult to ignite than other fuels we use for transport. LNG itself is not burned, only natural gas vapours will burn and only with an ignition source of 628°C. Natural gas also needs to have a concentration of 5-15% in air on oxygen to burn. When cold LNG comes in contact with warmer air, it creates a visible vapour cloud from condensed moisture in the air. As it continues to get warmer, the vapour cloud becomes lighter than air and rises. When the vapour mixes with air, it is only flammable when the mixture is between 5-15 percent natural gas. When the mixture is less than 5 percent natural gas, it doesn't burn. When the mixture is more than 15 percent natural gas in air, there is not enough oxygen for it to burn.

LNG vapour is non explosive in an unconfined environment and LNG (the liquid) is not flammable or explosive. Transportation takes place in double-hulled ships specifically designed to handle the low temperature of LNG. These carriers are insulated to limit the amount of LNG that evaporates. A majority of the world's supply comes from countries with the largest natural gas reserves: Algeria, Australia, Brunei, Indonesia, Libya, Malaysia, Nigeria, Oman, Qatar, Trinidad, and Tobago.

1.3.2 The LNG value chain

Basically, natural gas can be transported over long distances in two ways, either via pipeline or, after being liquefied, by means of LNG carriers. If transported as LNG by means of an LNG carrier, LNG can be

regasified in the importing country and can be used by the conventional natural gas consumers which are power plants, industrial consumers, and households.

In addition, there are small-scale consumers in the industry and the transport sector using LNG that is not regasified. In the transport sector, the potential LNG consumers are heavy duty road vehicles, inland navigation vessels, and seagoing vessels.

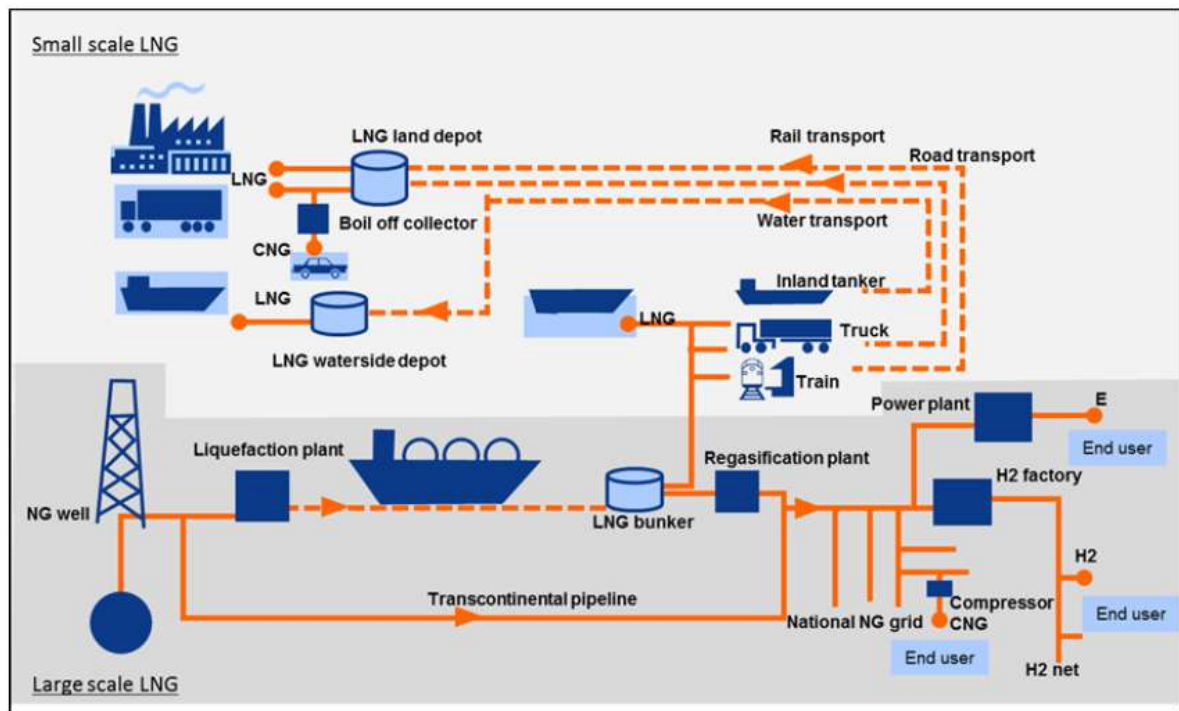


Figure 6 – Supply chain for small and large-scale LNG. Source: EC (2015)

In particular, the “Small Scale LNG” (or SSLNG) is defined as the way through LNG is administered directly in liquid form (with respect to the regasification operated in dedicated terminals and to the following introduction in gas form in the transport network). This category services related to SSLNG include different segments of a chain with multiple actors / operators (MISE, 2015).

The services of “Small Scale LNG” type, already operational or under development, may be provided through the following infrastructure (or installations):

- regasification terminals, offering mainly the following services:
 - re-loading, i.e. transfer of LNG from the terminal tanks to LNG carriers;
 - transshipment, i.e. direct transfer of LNG from one ship to another;
 - loading of LNG to bunker ships (barge/shuttle);

- loading of LNG to tanker trucks or ISO containers;
- loading of LNG to tanker rail wagon
- bunker ships (barge/shuttle) which provide LNG propelled ships (bunkering) or local costal depot;
- mini liquefaction plants for the transformation to the liquid state of the natural gas coming from the network, used to load tank trucks or ISO containers and/or barges/shuttles (if coastal plants);
- truck tankers or o ISO-containers which provide LNG propelled ships (bunkering) or local costal storages;
- local storages, supplied by tankers or ISO-container and/or barges/shuttles (if coastal storages) and used for:
 - loading of tanker trucks, ISO-container or barges;
 - coastal fuelling facilities for LNG propelled ships (bunkering);
 - fuelling facilities for LNG or CNG propelled vehicles;
 - satellite storage depot for industrial or civil use;

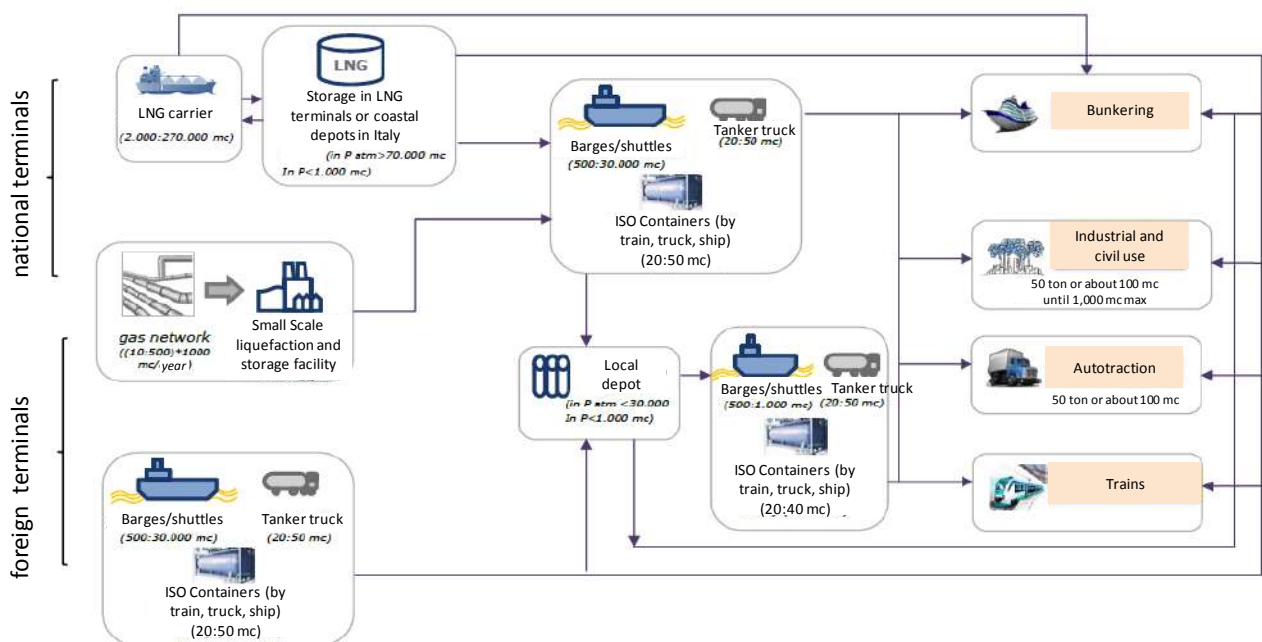


Figure 7 – Supply chain for Small Scale LNG. Elaboration on MISE (2015).

1.4 LNG Small Scale bunkering services

The US Department of Transportation Maritime Administration (Marad) has analyzed and compared (DNV GL, 2014)¹⁰ four potential bunkering options using LNG: Truck-to-Ship (TTS), Shore-to-Ship (PTS), Ship-to-Ship (STS) and Portable Tank Transfer.

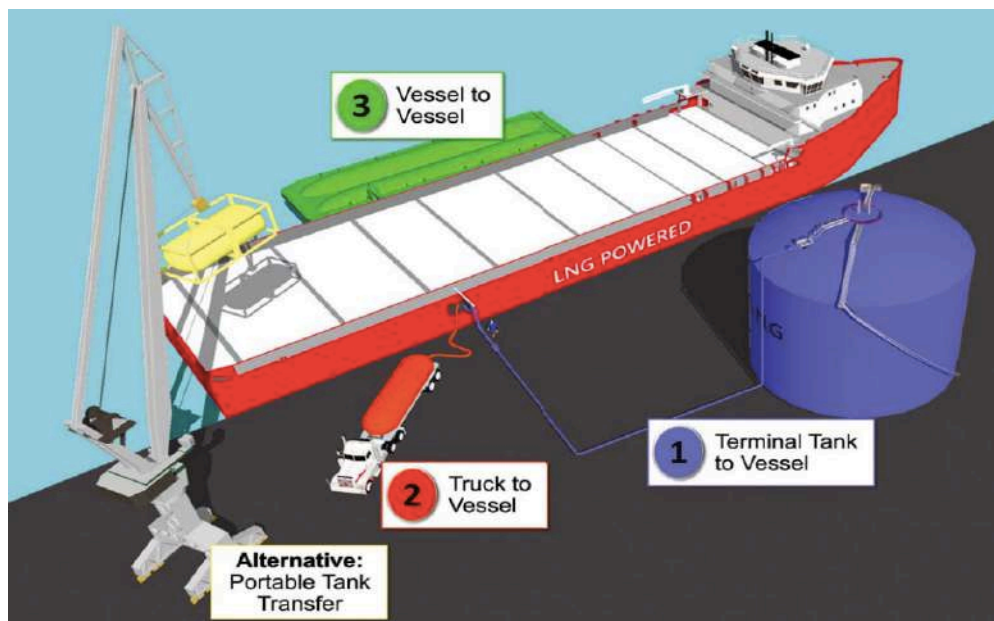


Figure 8 - Standard LNG Bunkering Options. Source: ABS (2016)

¹⁰ Cited in Ministero dello Sviluppo Economico, Documento di consultazione per una Strategia Nazionale sul GNL – ALLEGATO al capitolo 2, "APPROVVIGIONAMENTO E STOCCAGGIO GNL"

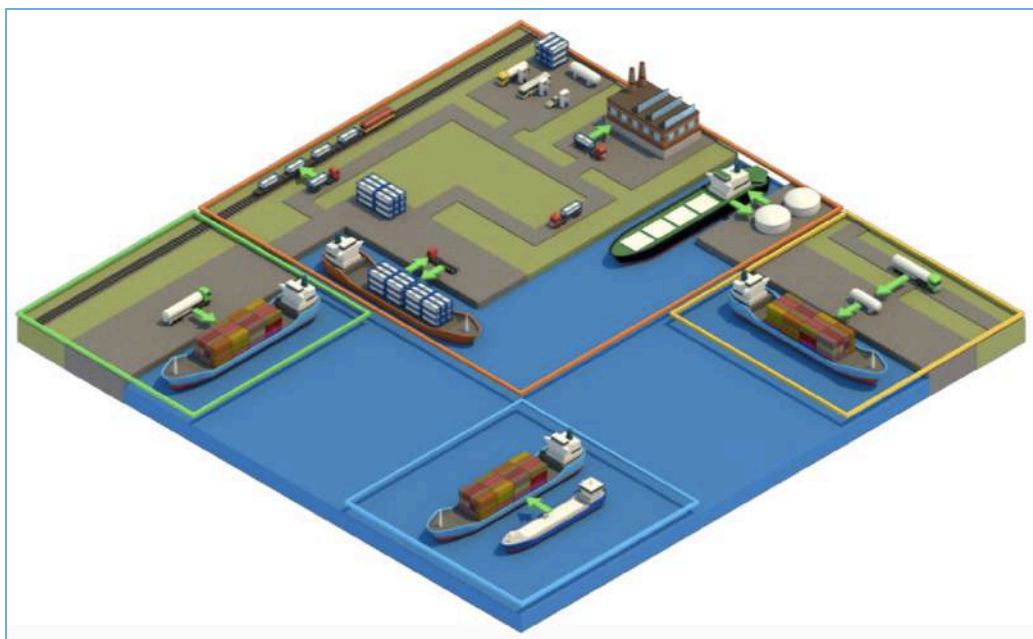


Figure 9 - Standard LNG Bunkering Options. Truck-to-Ship (green box); Ship-to-Ship (blue box); Shore-to-Ship ((yellow box); Portable Tank Transfer (orange box). Source: DNV GL, 2014.

1.4.1 Truck-to-Ship (TTS) bunkering

Truck-to-Ship (TTS) bunkering is the transfer of LNG from a truck's storage tank to a vessel moored to the dock or jetty. Typically, this is completed by connecting a flexible hose designed for cryogenic LNG service. Alternatively, a flexible connection arm can be used. A typical LNG tank truck can carry 40-50 m³ of LNG and transfer a complete load in approximately one hour.

TTS bunkering offers great flexibility to vessel owners, operators, and to bunkering site; in practice any jetty may be used; however, capacity and supply security can be limited. For vessels with small volume LNG fuel tanks, it can be used as a start-up solution to probe the bunkering market before making a large capital investment in LNG bunkering infrastructure. Its portability means that LNG can be supplied at nearly any location. As a result, the only limit geographically is identifying a port that will permit shoreside LNG bunkering from a dock or jetty.

The feasibility of transferring LNG TTS for very large volume transfers is limited by transfer rate and the number of trucks required. TTS bunkering has one of the lowest transfer rates at 50 m³/h.

According to the study, TTS bunkering has a strong, flexible position for delivering LNG to remote places or to smaller vessels where the duration and number of trucks needed for refueling is less impactful to the operation.

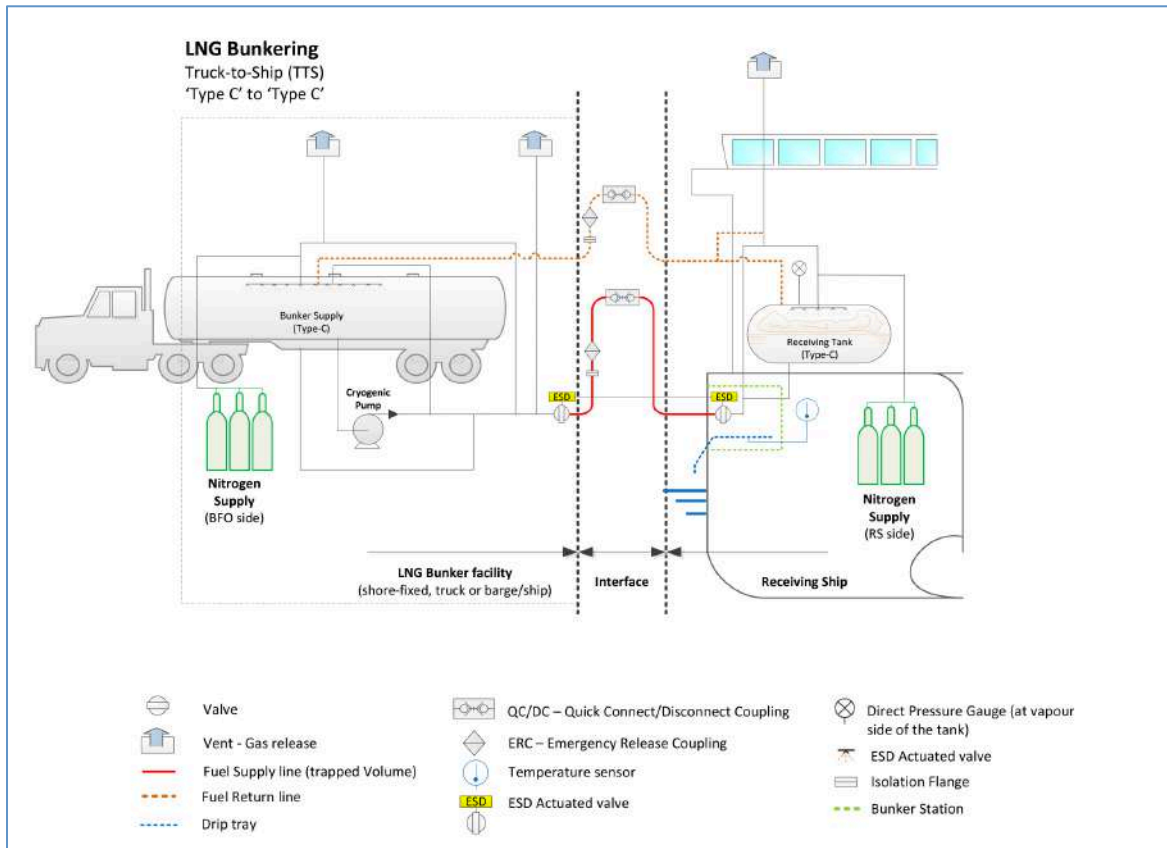
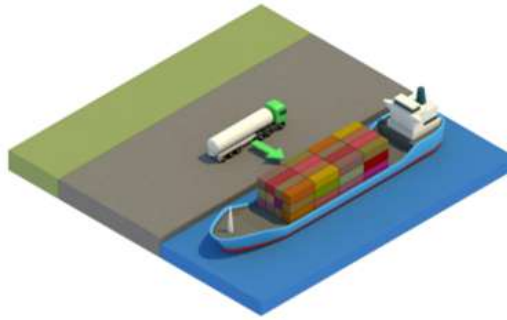


Figure 10 - Truck-to-Ship (TTS) bunkering option. Representation from MARAD Study (top) and layout scheme from EMSA (bottom)

1.4.2 Shore-to-Ship or Terminal-to-ship via pipeline (PTS) bunkering

In the Shore-to-Ship (or Terminal-to-ship via pipeline, TPS, as it is called in other studies) bunkering option, LNG is transferred from a fixed storage tank on land through a cryogenic pipeline with a flexible end piece or hose to a vessel moored to a nearby dock or jetty. This is also referred to as pipeline-to-ship.

These facilities have scalable onsite storage such that designs could be capable of performing bunkering of larger volumes than TTS or with portable tanks.

LNG may be transported to the facility by truck, rail, or bunker barge, and may be transported from a

remote liquefaction facility. LNG may be produced (i.e., converted from gas to liquid) at a small-scale production facility known as a liquefaction facility. In principle, small-scale LNG liquefaction facilities may provide LNG bunkering onsite. The TPS option has good design flexibility that can meet the needs of many customers. TPS bunkering can potentially supply much higher flow rates than TTS bunkering.

Although the TPS option has great flexibility in the design for transfer rate and volume, it is the least flexible with respect to geography. It must be sited at a fixed location, relatively close to the dock or jetty. In addition, as a fixed installation, vessels must make the necessary arrangements to be at the loading berth for transfers. For vessels with other activities (i.e., cargo transfers) in the port, bunkering occurs at the same time as the other activity to reduce the time spent in port. If TPS bunkering locations cannot perform simultaneously with other activities, it will extend the time in port and reduce the TPS option viability.

An intermediate storage location with bunkering capability is a viable alternative (i.e., a smaller LNG tank supplied by LNG tank trucks). Onsite storage at the bunkering facility could be replenished by truck, rail, pipeline, or directly by a small-scale liquefaction plant receiving natural gas.

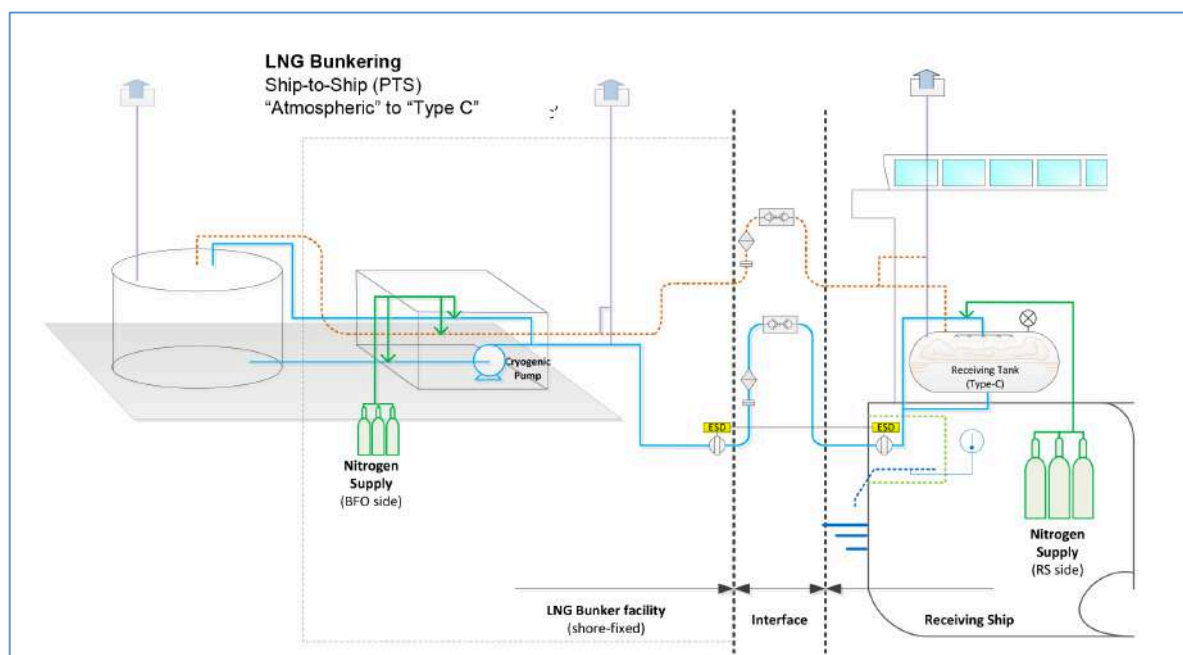
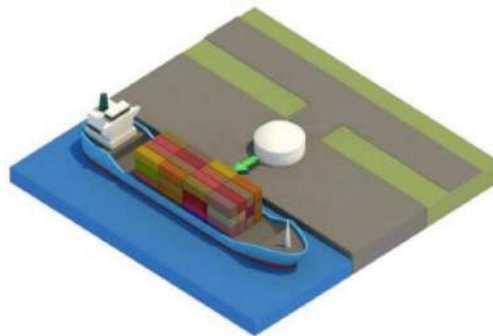


Figure 11 - Terminal-to-ship (TPS) bunkering option. Elaboration on DNV GL's Study (top) and layout scheme from EMSA (bottom)

1.4.3 Ship-to-Ship (STS) bunkering

Ship-to-Ship (STS) bunkering is the transfer from one vessel or barge with LNG as cargo to another vessel for use as fuel. This bunkering approach can be utilized in a number of different ways. STS bunkering offers a wide range of flexibility on quantity and transfer rate. Also included in this typology is the transfer of LNG from a bunker barge to LNG-fueled vessel. Bunker vessels and barges also have the greatest flexibility in location of bunkering. There are two types of STS bunkering operations: one is performed at the port, and the other is carried out at sea. STS bunkering can enable additional logistical flexibility by conducting bunkering with other activities while docked, including cargo transfers and embarkation/disembarkation. STS bunkering can also enable passing vessels to refuel without entering the port.

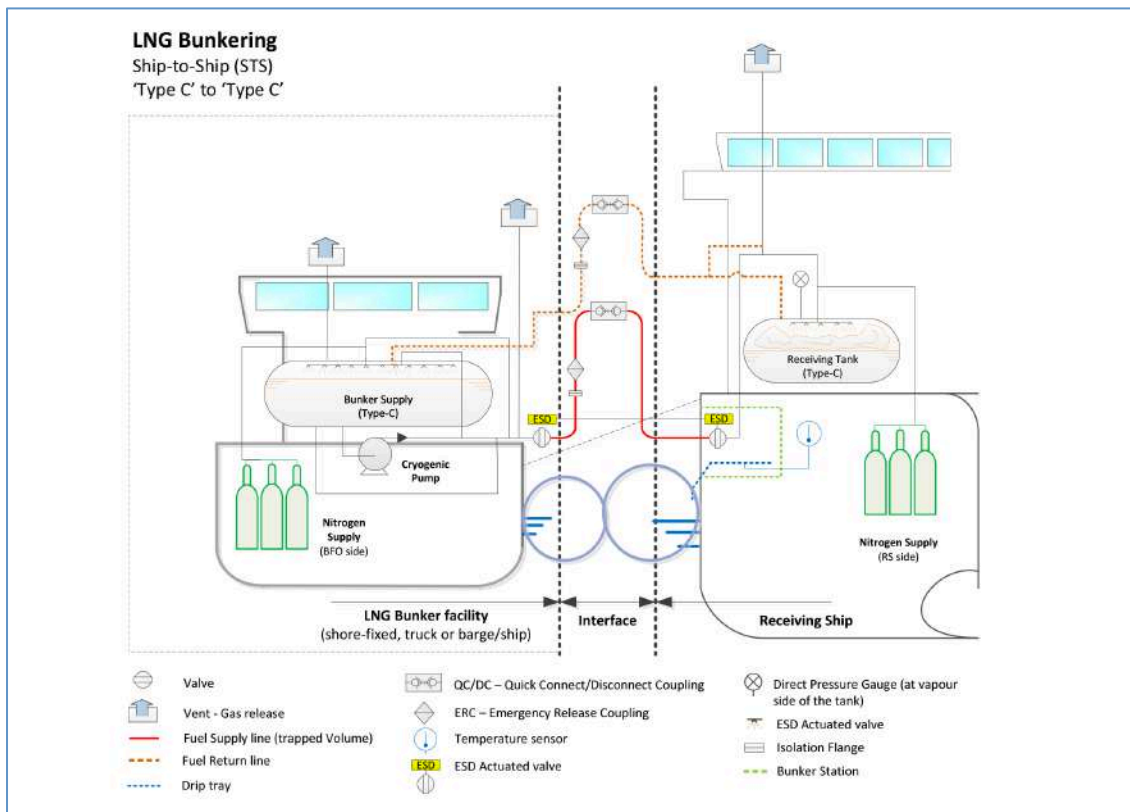


Figure 12 – Ship to Ship (STS) bunkering option. Representation from DNV GL's Study (top) and layout scheme from EMSA (bottom)

In STS bunkering, three different kind of ships are usually employed:

- bunker vessels;
- feeder vessels;
- barges with or without self propulsion.

Bunker vessels allow for smaller and flexible movements within the port than feeder vessels, having capacity between 1,000 and 10,000 mc. Feeder vessels have their basic aim in the regional distribution of LNG from large import terminals to points along the coastline and have typical capacity ranging from 7,000 to 20,000 mc. barges (with or without self propulsion), given their limited dimensions, have an efficient/quick turnaround at loading/discharging ports.

A certain amount of LNG bunker barges is being designed/projected. A great advantage in employing barges is the lower amount of investment required with still a flexible and mobile solution. The barge can be towed with a tug to the bunker station.

Some cases of bunkering activities and/or new bunker vessels and barges are reported below.

Stockholm – Seagas bunker ship

In 2013 Viking Line introduced a new vessel into service, the MS Viking Grace, a large passenger ferry on the Turku – Stockholm route, running on LNG. Bunkering takes place while the vessel is at berth in Stockholm.

LNG is transported from the AGA LNG terminal in Nynäshamn to Stadsgården in Stockholm, where Viking Grace arrives early in the mornings. Bunkering is performed around six times a week using a purpose-built bunkering vessel that draws up alongside Viking Grace. Ship-to-ship bunkering, and not truck-to-ship, is used because the ferry only stays at berth for one hour.

It must be noted that LNG bunkering in Stockholm is specifically designed for Viking Grace and that the two vessels were purpose-built for each other. If more LNG vessels were brought into operation, the LNG infrastructure, according the port authority itself, would need to be further developed.

The bunker vessel, named SEAGAS, is a ferry converted with the aid of TEN-T funding with capacity of 187 mc and a bunkering rate of about 150 m³/h. In preparation for bunkering, Seagas is fuelled by 3 trucks. Each truck takes about one hour, i.e. for the vessel 2,5-3 hours are needed to bunker it with LNG. Seagas bunkering vessel is located and fuelled at harbour Loudden in Stockholm port. The fuelling procedure from

ship-to-ship takes in total 60 minutes, of which 45 minutes are dedicated to transfer of LNG from one ship to the other, and 15 minutes are necessary for pre-fuelling and post-fuelling measures.¹¹



Figure 13 - Seagas during bunkering the Viking Grace (left), Seagas (right)

Other bunkering experiences in Scandinavia

The Coral Energy (15,600 mc) made its first bunkering operation in September 2015 transferring LNG to the product tanker Ternsund at Gothenburg in Sweden. The LNG carrier is normally used to feed LNG to distribution terminals in Europe.



Figure 14 - Coral Energy during bunkering operations

Coral Anthelia, with capacity of 6,500 mc, was tested in October 2015 in the port and LNG production plant of Risavika (Norway) bunkering the chemical tanker Bit Viking.



Figure 15 - Coral Anthelia during bunkering operations

Skangas will start operating a new bunker vessel in early 2017. The new Skangas bunker vessel M/T Coralius will have a capacity of 5,800 mc. It will provide both ship-to-ship bunkering and terminals feeding¹².



Figure 16 - New Skangas bunker vessel under construction

The LNG tanker “Pioneer Knutsen” (1,100 m³), which primarily acts as an LNG tanker, has also been involved in STS bunkering of LNG-fuelled ferries in Norway.

¹² Source: www.skangas.com/en/news/gothenburg-sts-bunkering



Figure 17 - Pioneer Knutsen

Jacksonville (Florida) – Clean Jacksonville

Conrad Shipyard is realizing a new LNG bunkering barge, the “Clean Jacksonville”, expected to be delivered in the second quarter of 2017. The barge is currently under construction (design by Bristol Harbor Group), with a single tank of 2,200 mc. The barge will transfer LNG at 500 mc/hour and is destined to carry LNG for Tote Maritime’s Isla Bella and Perla Del Caribe container ships serving Puerto Rico from Jacksonville in Florida.¹³



Figure 18 - Clean Jacksonville design (left) and under construction (right)

¹³ Source: www.cleanmarineenergy.com/cme-portfolio/jax-lng-executes-engineering-contracts; hhpinsight.com/marine/2015/07/gtt-releases-lng-bunker-barge-details; hhpinsight.com/marine/2016/03/tote-cme-bunker-barge-launched-in-texas

Advantages	Disadvantages
<ul style="list-style-type: none"> • Refuelling at sea is possible; eliminates the need to come into a port; • In port mobility allows for transfers to take place in protected areas or away from sensitive areas and critical infrastructure; • Large transfer volumes are possible at high bunkering flow rates; • Transfer rates approach shore-to-ship bunkering capabilities; exceed truck-to-ship option; • Remote locations reduce/eliminate potential exposure to vulnerable targets. 	<ul style="list-style-type: none"> • Exposes both vessels to full sea state • Currents • Wind • Waves • Higher investment and operational cost than shore and truck-to-ship options • Requires some shoreside infrastructure for loading LNG as cargo

Table 6 – Advantages and Disadvantages of Ship-to-Ship Bunkering of LNG. Source: elaborated from US Department of Transportation Maritime Administration, DNV GL, Liquefied Natural Gas (LNG) Bunkering Study, September 2014.

1.4.4 Portable ISO-tank transfer

Portable tanks may be used as portable fuel storage. They can be driven or lifted on and off a vessel for refueling. The quantity transferred is flexible and dependent upon the number of portable tanks transferred. A 40-foot ISO intermodal portable tank can hold on average 43 m³ of LNG, meaning around 18,5 tonnes.

Portable tank infrastructure is not entirely dependent upon demand from vessel bunkering. Interest in portable tanks arises from a wide array of potential uses for them. Like other portable fuels, they can be transported many different ways (by truck, rail, and cargo vessel). They can be stored for periods and utilized by many potential customers (e.g., industrial, shipping, CNG refueling station supply).

In principle, portable tanks offer the same flexibility in availability and transportability as the TTS option. However, to utilize portable tanks onboard a vessel, the tank and vessel designs must be compatible (i.e., IGF Code, class rules).

1.4.5 Multiple/simultaneous TTS connection

The option for common manifolds is considered also in the EMSA Guidance on LNG bunkering (EMSA, 2018), and has been first featured in IACS Rec. 142 where it is mentioned: “Depending on the shore side arrangement it may be possible to increase the bunker rate to some extent by simultaneous bunkering from multiple trucks via a common manifold”.

A number of solutions are already available on the market, some of which are described hereinafter in order to highlight the flexibility of this kind of systems.

Gas and Heat has completed the design, production and assembly of a multiple refueling solution called LNG4Speed (patent pending), specifically designed to simultaneously connect four LNG tanker trucks in truck-to-ship bunkering operations, allowing the supply of the ship in a sixth of the time compared to traditional refueling with one tanker/ISO-container at a time.

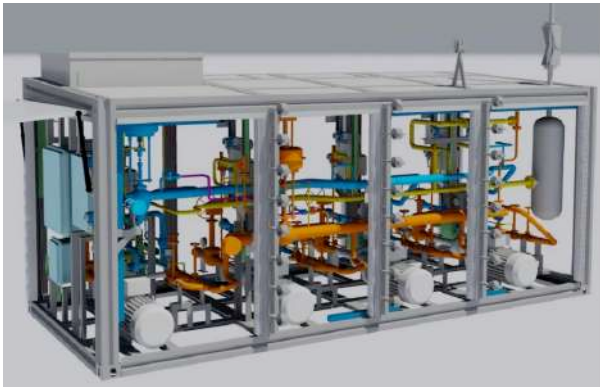


Figure 19 - Rendering (left) and realized prototype (right) of the multiple refueling solution "4SPEED". Gas&Heat (2017)

The skid is currently employed by a Canadian shipping company that is now able to correctly manage the lack of LNG infrastructure within the operating regime of its units.

Each vessel has a skid on board that can be unloaded at the dock and operated by the ship's crane. The skid is connected by hoses to both the ship and the four trucks at the time of the bunkering operation. After the completion of the operation (following purging and draining), the Skid will be either left on the quay, or loaded and secured on board the ship, to then be used in the next port of call. For this purpose, the design focused on weight and volume reduction allowed to obtain a unit with final dimensions equal to those of a 20-foot container.



Figure 20 - Bunkering operations when testing the skid (left) and a reassembled unit ready for transport as a 20-foot container (right). Gas&Heat (2017)

Among the multiple connectors for LNG bunkering in truck-to-ship mode, the solution of the Danish company Kosan Crisplant (MAKEEN Energy) is also currently available on the market, which has already marketed the product to the international logistics group NIJMAN/ZEETANK that operates in the Netherlands. The Y-piece is designed to function as an adapter that splits the bunkering line in two, allowing LNG to be transferred to the ship by two tankers simultaneously.



Figure 21 - Kosan Crisplant's LNG Y piece rendering (left) and testing in real life TTS operation (right)

Furthermore, adding a second element to the line, the potential number of tankers that can discharge LNG simultaneously increases to four, reducing the bunkering time by 75%, guaranteeing capacities up to 120 m³/h. Designed to achieve the highest degree of flexibility and lightness, this type of bunkering component is a highly mobile solution: its limited weight allows it to be lifted by only two crew members' hand and then transported on any standard trailer without the need for special machinery or cranes.

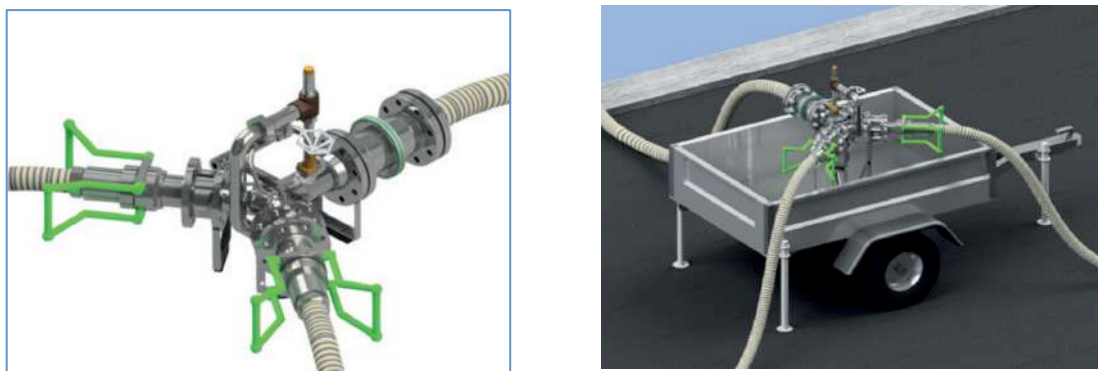


Figure 22 - Kosan Crisplant's LNG Y piece connection detail (left) and easy handling solution on quay (right)

The component can easily adapt to any type of trailer, but above all the non-return valves and an innovative bleeding system allow to disconnect and change trailers during the filling operation, without interrupting the bunkering operation.

1.4.6 Brief comparison

In order to summarize the main aspects characterizing each bunkering solution, and thus allowing for a quick comparison, a SWOT analysis has been elaborated for every option and is hereby proposed, taking advantage from EMSA guidance while adding personal perspective.

Terminal-To-Ship Bunkering (via modular mid-to-large Small Scale Terminal – 1000-20.000m³ of LNG storage capacity)

STRENGTHS	WEAKNESSES
<ul style="list-style-type: none"> – Possibility of supplying greater volumes of LNG with a higher rate; – Suitable for serving also the maritime demand; – Good option for ports that have stable and long-term bunkering. 	<ul style="list-style-type: none"> – High initial investment costs; – Need for high market volumes; – Complex logistics involving various operators and infrastructures (LNG terminals, bunker ship, depot, secondary transport via tankers, final customer). –
OPPORTUNITIES	THREATS
<ul style="list-style-type: none"> – Plan the implementation into phases to follow the evolution of the market; – Implement an adequate involvement of the parties and an information campaign to prevent problems in the authorization process; – Make use of European funds and a combination of national and EU financial instruments to improve the sustainability of the investment. 	<ul style="list-style-type: none"> – Obstacles to the authorization process; – Price dependent on the world LNG market; – It could be difficult to receive larger tanker at the port.



Table 7 – SWOT of Terminal-To-Ship bunkering option (a). Elaboration and integration on EMSA (2018)

Terminal-To-Ship Bunkering (via small facility of less than 1000m³ of LNG storage capacity)

STRENGTHS	WEAKNESSES
<ul style="list-style-type: none"> – Reduced initial investment, engineering costs and delivery time of ready to use solutions; – Sustainable even at low market volumes; – Suitable for serving the trucking and off-grid application. 	<ul style="list-style-type: none"> – Expansion of storage capacity not always feasible if designed for too small volume and in limited spaces; – Inability to follow the evolution of the market in the event of exponential demand growth.
OPPORTUNITIES	THREATS
<ul style="list-style-type: none"> – Plan entry into the market (and subsequent installation) with a minimum demand of around 8,000 tons a year; – Consider future expansion carefully in the FEED stage in order to prevent future constraints and prevent the threats. 	<ul style="list-style-type: none"> – Exclusion from the market by larger terminals able to offer more competitive rates.

Table 8 – SWOT of Terminal-To-Ship bunkering option (b). Elaboration and integration on EMSA (2018)

Intermodal ISO-container bunkering

STRENGTHS	WEAKNESSES
<ul style="list-style-type: none"> – Absence of interface bunkering operations; – Simplification by exempting operations from hoses and other operational aspects; – Leveraging of intermodal transportation; – Limited negative public perception; 	<ul style="list-style-type: none"> – Connections onboard need to comply with strict construction regulations; – Limited volumes available in 20-40 m3 containers; – Only suitable for a limited type of ships; – Requires pre-installation of LNG fuel installation; – Time limitation of stay on the quay;
OPPORTUNITIES	THREATS
<ul style="list-style-type: none"> – Potential advantages linked to intermodality; – Potential use to feed co-generation plants in port; – Establish specific storage zone in the port's ADR areas. 	<ul style="list-style-type: none"> – Benefits deriving from intermodality prevented in the absence of adequate railway connections in port.

Table 9 – SWOT of intermodal ISO-container bunkering option. Elaboration and integration on EMSA (2018)

Truck-To-Ship bunkering (with and without Multiple/simultaneous TTS connection systems)

STRENGTHS	WEAKNESSES
<ul style="list-style-type: none"> – Operational flexibility and logistics suitable for low market volumes; – Limited infrastructure requirements (economically sustainable in the initial phase); – Suitable for trucking and off-grid application; – Possibility of adaptation to the customer's needs based on the volumes requested; – Possibility to adapt to different security requirements; – Possibility of serving different LNG fuel users; – Limited permanent occupation of the quay space; – Limited negative public perception. 	<ul style="list-style-type: none"> – Limited capacity of trucks: approximately 40-80 m3 is likely to dictate multi-truck operation; – Limited flow-rates (900- 1200l/hr) without multiple connection; – Significant impact on other operations involving passengers and/or cargo; – Limited movement on the quay-side, mostly influenced by the presence of the bunker truck(s); – Exposure to roadside eventual limitations (permitting, physical limitations, traffic related, etc.).
OPPORTUNITIES	THREATS
<ul style="list-style-type: none"> – Use of multiple connections to ensure greater volumes; – Use of LNG as an alternative fuel for road tankers to minimize emissions and increase positive social perception; – Provide dedicated / preferential access routes for tankers arriving at the facility. 	<ul style="list-style-type: none"> – Dependence (currently) on the large European on-shore LNG terminals; – Failure of the multiple connection, in the absence of a back-up unit, would nullify the refueling operations; – Increase in road traffic by road arteries near the port could increase negative perception.

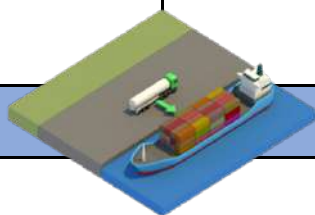


Table 10 – SWOT of Truck -To-Ship bunkering option. Elaboration and integration on EMSA (2018)

Ship-To-Ship bunkering (with a typical LBV of around 7.500 m³ LNG storage capacity)

STRENGTHS	WEAKNESSES
<ul style="list-style-type: none"> – Generally does not interfere with cargo/passenger handling operations. Simultaneous Operations (SIMOPS) concept is favoured – Most favourable option for LNG bunkering, especially for ships with a short port turnaround time – Larger delivery capacity and higher rates than TTS method. – Operational flexibility – bunkering can take place alongside, with receiving vessel moored, at anchor or at station – No construction permits required, thus delivery time are quite certain and ruled by owner/shipyard/manufacturers contract, allowing to decide almost exactly when entering the market – Limited negative public perception. 	<ul style="list-style-type: none"> – Initial investment costs involving design, procurement, construction and operation of an LNG fuelled vessel/barge – Significant impact in lifecycle cost figures for the specific LNG bunker business – Limited size for bunker vessel, conditioned by port limitations.
OPPORTUNITIES	THREATS
<ul style="list-style-type: none"> – Synergy with coastal storages and/or satellite plants to guarantee total operating flexibility and full market coverage – LNG fuelled technology to maximize energy efficiency, environmental performance and cost-effectiveness. 	<ul style="list-style-type: none"> – The bunker ship is able to follow the market, thus it is less linked to a single port/location (in this case the threat is not for the ship but for the established system in a single place).



Table 11 – SWOT of Ship-To-Ship bunkering option. Elaboration and integration on EMSA (2018)

2 LNG deployment as alternative transport fuel in Italy

2.1 National legal framework

2.1.1 Italian transposition of Alternative Fuels Infrastructure Directive

The transposition of the AFI Directive has undergone through a number of steps that can be recapped as follows:

- A law of European delegation 2014 – Law No. 196 of July 9, 2015 published in the Official Journal No. 176 of July 31, 2015 gave mandate to the Government for transposing the Directive;
- For this purpose a specific working group was established within the Ministry of Infrastructure and Transport, which has worked on the legislative decree of implementation, involving also other Ministries (Economic Development, Environment, Interiors, Economy and Finance), stakeholders and experts;
- The first National Plan of infrastructure for charging vehicles powered by electricity had been adopted during 2013/2014. The plan has been updated during 2015/2016. The final version will be published in the next days;
- The public consultation promoted by the Ministry of Economic Development, for the preparation of the National Strategic Plan of LNG, was launched at the end of June 2015. The public consultation was completed in February 2016;
- The findings of these two plans have been taken into consideration within the legislative decree implementing the Directive;
- Similar approach has been followed also for hydrogen and CNG. The results of this process were used to prepare the legislative decree.

Finally, the Italian Legislative Decree n. 257 of 16th December 2016 – *“Disciplina di attuazione della direttiva 2014/94/UE del Parlamento europeo e del Consiglio, del 22 ottobre 2014, sulla realizzazione di una infrastruttura per i combustibili alternativi”* – concerning AFID implementation was published on the Italian Official Journal (S.O. n. 3 Gazzetta Ufficiale - Serie Generale n. 10) on 13 January 2017.

This legislative decree provides the minimum requirements for the deployment of alternative fuel infrastructures including re-charging points for electrical vehicles and refuelling points for LNG and CNG.

2.1.1 Italian Strategic National Framework for LNG

The legislative decree introduces (art. 3, para 2) the Strategic National Plan (Quadro Strategico Nazionale - QSN) which, provided as Annex III to the legislative decree, is organised in four sections:

- Section A – electrical supply for transport;
- Section B – hydrogen supply for road transport;
- Section C – natural gas supply for transport and other uses, including inland navigation, maritime and road transport;
- Section D –GPL supply for transport.

As well underlined by the European Commission¹⁴, the Italian NPF fully addresses the requirements of Article 3. It contains an extensive discussion of the current state, and future scenarios, for alternative fuels in the transport sector. However, it does not establish hard targets for all fuels and modes, because the NPF uses scenario dependent projections relying on 'expected trends' or 'evolution' rather than real quantitative targets.

As far as natural gas is concerned, the Italian NPF puts a lot of emphasis on CNG, for which, already today, Italy has a dense network of public refuelling points, especially in the northern regions.

Regarding LNG, the Italian NPF considers the development of a LNG infrastructure for maritime applications as strategic and critical in the context of the implementation of the Directive. Plans for its development, including designing of storage quantities in all 14 maritime TEN-T Core Network ports and beyond, are part of the NPF and can be considered exemplary.

Regional and local interests have been considered in the evaluation of the measures, as well as industrial and public R&D stakeholders. In fact, regional authorities and municipalities play a critical role in ensuring the implementation of the actions, having jurisdiction on infrastructure for highways, respectively for local infrastructure. A particular attention in the Italian NPF has been dedicated to the island Sardinia, which at the moment is the only region of Italy deprived of a NG distribution infrastructure. Evidence of Italy's collaboration with other Member States has been found, mainly in the frame of European projects, especially under the TEN-T and CEF Programmes.

¹⁴ <https://ec.europa.eu/transport/sites/transport/files/2017-11-08-mobility-package-two/ms-fiches.pdf>

2.2 Overview of GAINN_IT: the Italian Initiative for LNG infrastructure deployment

GAINN_IT is the National Initiative promoted by the Italian Ministry of infrastructure and transport for the deployment of the alternative fuels network in Italy, in accordance with the objectives set out in the Directive 2014/94/EU on Alternative Fuels Infrastructure (hereinafter “AFID”).

The GAINN_IT Global Project specifically aims to trigger investments in sustainable transport and support the deployment of a continued network of alternative fuels infrastructure, with particular reference to LNG-related one, at national and European level.

Pursuing such an objective, the GAINN_IT target fits with the purposes of the European Clean Power for Transport Strategy to promote infrastructure for supplying alternative fuels as a contribution to a 60% reduction in GHG emissions from transport by 2050, in line with the objectives set out in the White Paper for Transport and the 2020 Strategy as well. In addition, the deployment of sustainable alternative fuels will be also beneficial in helping urban areas to meet Union air quality obligations, especially those related to particulate matter (PM10) levels as required by the National Policy Framework.

The GAINN_IT Global Project, following the results of the COSTA Action (2011-EU-21007-S) started in September 2015 by the Italian Ministry of Infrastructures and Transport (MIT), aims at conceiving, defining, prototyping, testing, validating and deploying, in the period 2017-2030, the Italian Network of Infrastructures of Alternative Fuels for maritime and surface transport as requested by AFID. In doing so, the GAINN-IT network will contribute to the achievement of “cross border continuity” of alternative fuels supply. The GAINN-IT global project mainly addresses LNG as an alternative fuel for both road and maritime transport.

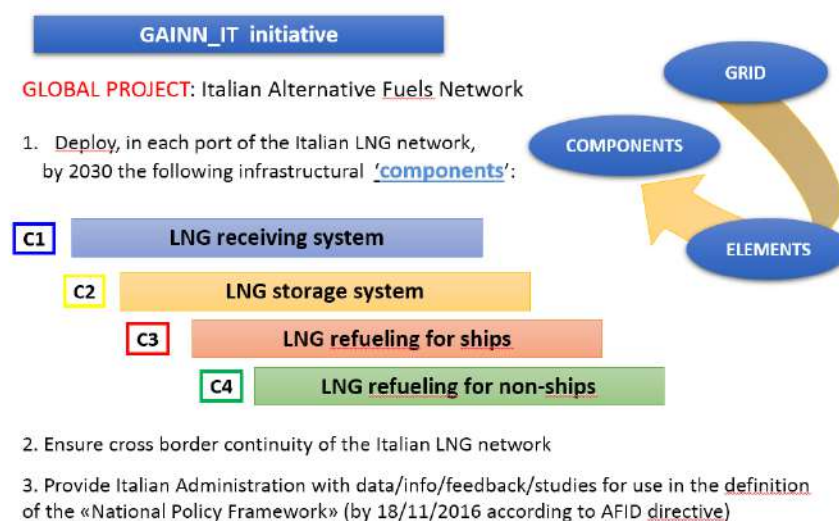


Figure 23 - GAINN_IT Initiative's aims

Completing the GAINN_IT Global project requires 4 development phases:

- ✓ Step 1: study and definition of 3 pilot national LNG grids (Tyrrhenian-Ligurian, South Italy and Adriatic-Ionic) and of the standard technical specification of the LNG components (LNG receiving system, LNG storage and local distribution system LNG ship bunkering system , LNG vehicles refuelling. This step has been performed within the GAINN4CORE (2014-IT-TM-0450-S) and GAINN4MOS (2014-EU-TM-0698-M) Actions.
- ✓ Step 2: prototyping of the 3 pilot LNG grids of a set of standard LNG components (see above) and standard LNG refuelling operations and connections. This is being done in both GAINN4CORE, GAINN4MOS ongoing Actions;
- Step 3: provide for a stimulus of LNG demand in the short term start-up phase (2017-2022) through the roll-out start up phase for the market uptake and the of a minimum coverage of the alternative fuels network as required by the AFI Directive: this will be done with GAINN_IT further Actions.
- Step 4: roll-out and integration of the 3 Italian pilot LNG grids into the full-scale deployment of the Italian network of infrastructures for alternative fuels within the 2030 roadmap.

In this context, the study phase completed at the end of December 2016 and the prototyping and the roll-out start-up phase being implemented by GAINN_IT Actions constitute the fundamental GAINN_IT Implementation Pipeline that, after the “study”, “prototyping” and “roll-out start-up” steps, is ready for the market roll-out towards the complete cross-border and interoperable LNG network deployment.

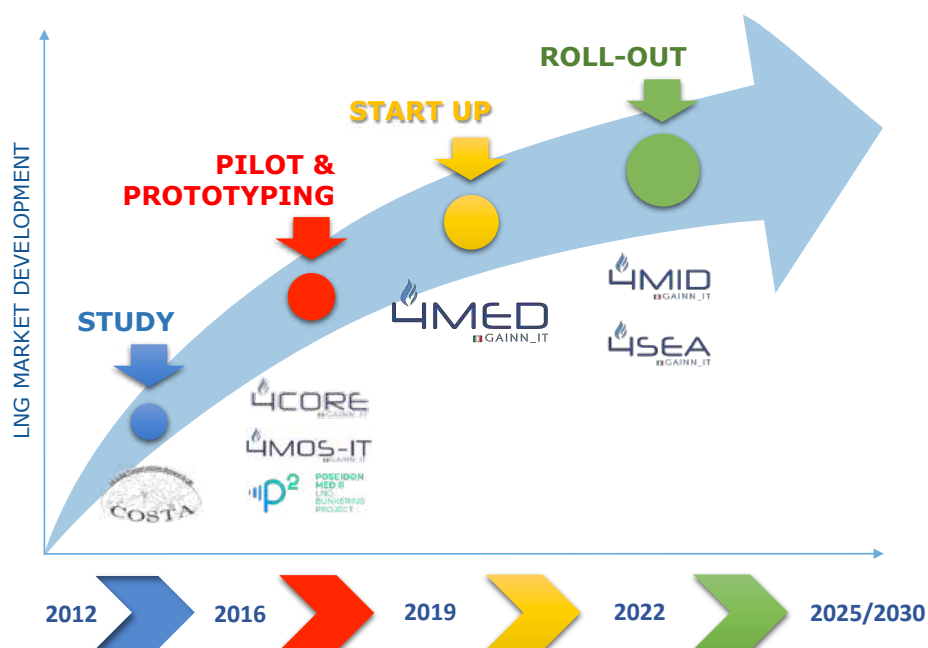


Figure 24 - GAINN_IT Implementation Pipeline

2.3 Ongoing Actions within the GAINN_IT implementation pipeline

Recalling that this study stems from the knowledge and experience the authors gained within the course of EU-funded trans-national projects, this paragraph summarizes the ongoing Actions falling within the GAINN-IT Initiative previously described, in order to provide useful insights and a unique perspective of the real state of deployment, from the study and piloting phase up to the roll-out, of the LNG infrastructure in Italy.

At present, the project under implementation included in the GAINN_IT Initiative are the following:

- GAINN4CORE Action
- GAINN4MOS Action
- Poseidon Med II Action
- GAINN4MED Action
- GAINN4SEA Action
- GAINN4MID Action

Exception made from the Poseidon Med II Action, for all the other Projects the author is being involved in the technical management team of one of the most important partners on the Italian side, namely Consorzio 906, which is involved in quality as Implementing Body of the Italian Ministry of Transport and Infrastructure and, in some cases, directly as Project Coordinator.

Keeping in mind the respective Projects' objectives and results is crucial for this study as all of them may have an impact on the future deployment of LNG for the selected case study this document refers to.

2.3.1 GAINN4CORE Action

GAINN4CORE has been selected for funding under the 2015 CEF Multi-Annual Call and contributes to the GAINN_IT Initiative objectives by defining, prototype and test two of the three Italian LNG grids, both the Tyrrhenian-Ligurian and the Adriatic-Ionian grids.

The port elements involved within the GAINN4CORE Action are the Core Ports of Genova, La Spezia, Livorno (Tyrrhenic-Ligurian Grid), Ravenna and Venezia (Adriatic-Ionic Grid).

Within GAINN_IT Step 1, GAINN4CORE defined the technical specifications of the following LNG components:

- Component 1: LNG receiving system and related ancillaries (C1);
- Component 2: LNG storage and local distribution system and related ancillaries (C2);
- Component 3: LNG ship bunkering system and related ancillaries (C3);

- Component 4: LNG vehicles (non-ships) refuelling system and related ancillaries (C4).

The specific objectives of the Action can be summarized as follows:

- define the complete Italian LNG grid in order to offer an integrated alternative fuel infrastructure;
- create a synergy effect by preparing Italian ports and related hinterlands for LNG and by providing an alternative fuel for ships as well as land vehicles.
- generate an initial land and maritime demand for LNG as a bunker fuel, thus providing strong impulse to the related supply chain;
- initiate pilot infrastructures in order to store, distribute and refuel ships and other vehicles and test them in real life trials;
- share and disseminate the project results with public and private stakeholders;
- meet the needs and explore the potential of neighboring regions.

2.3.2 *GAINN4MOS Action*

GAINN4MOS is a twinned Action among a number of Member States which contributes to the implementation of the LNG bunkering project in the Atlantic and the Mediterranean by:

- Providing the core ports of Koper, La Spezia, Venezia, Fos-Marseille and Nantes-Saint Nazaire with initial pilot infrastructures (in the first 3 cases) and fully operational LNG bunkering stations (in the last 2 cases) required to comply with Directive 2014/94/EU on the deployment of alternative fuels infrastructure.
- Providing tested technologies that can be used to retrofit and/or build a large percentage of the short-sea fleet deployed in the EU Atlantic and Mediterranean.
- Proving that bunkering barges, tugboats, general cargo and pax or ro-pax types of vessels can be successfully retrofitted for them to use LNG as marine fuel and that financial feasibility analyses for their operating companies after the indicators obtained in real life pilots are taken into account confirm the convenience of this choice to external sea carriers.
- Paving the way for the implementation of LNG as fuel for ship and port machinery.
- Increasing the competitiveness of port services and shipping by reducing their fuel operational costs.
- Strengthening new EU niche markets associated to LNG.
- Providing involved Member States with the practical and operational background, experience and

results necessary to deal with the challenges posed by the Sulphur Directive and by the Alternative Fuel Infrastructures Directive.

One of the most relevant achievements of the GAINN4MOS at the time of writing is the realization of the first Dual Fuel LNG Ro-Pax ferry of the Mediterranean Sea, namely the ELIO ship of the Caronte&Tourist shipping line, which has been launched at the end of 2018 and is now operating in the Messina Strait (Italy).

The vessel, with a low resistance hull, is a double-ended seven-decks ferry designed to operate in EU Class D areas able to carry passengers, private cars, trucks and trailers, with a maximum capacity for 290 private cars, 1500 people and 35 trucks. It uses 3 main Wartsila 6L34DF engines of 3,000 kW each will be fed with LNG stored in 150-cbm anti roll tanks and two Rolls Royce AZIPULL100 CP engines of 2,500 kW each, which will allow a cruising speed of 12.5 knots. Service and maximum speeds are respectively 12.5 and 15 knots.

The ship is Italian flagged and RINA classed with Gas Fuelled notation (IGF compliant).



Figure 25 – Rendering (left) and picture in operation (right) of the LNG ferry ELIO. Source: GAINN4MOS Action

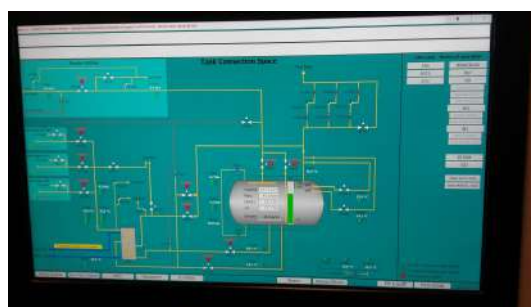


Figure 26 – ELIO's control room displays, visited within the GAINN4MOS Action

Design:	LMG 290-DEG	Type:	Ferry
Name:	Elio	Owner:	Caronte & Tourist
Year built:	2018	Yard / no:	Sefine / 30
Length over all:	133.6 m	Beam:	21.5 m
Depth:	9.1 m	Speed:	18.5 knots

Table 12 – Main technical data of the LNG fuelled Ro-Pax ferry ELIO built within the GAINN4MOS Action

2.3.3 *Poseidon Med II Action*

Poseidon Med II aims to contribute to reducing negative impacts of heavy fuel oil powering and to facilitate the implementation of the requirements of a number of EU Directives regarding alternative fuels for a sustainable future in the shipping industry.

The specific objectives of the project can be summarized as follows:

- facilitate the adoption of the regulatory framework for the LNG bunkering
- design the extension of Revithoussa LNG terminal
- design and construct an LNG fuelled specific feeder vessel
- implement technical designs and plan approvals for the retrofit/new building of LNG fuelled vessels and for additional ports' infrastructure for bunkering operations
- examine potential synergies with other uses of LNG
- develop a sustainable LNG trading and pricing pattern
- develop financial instruments to support the port and vessel installations
- develop synergies with other sectors (mainly Energy) that will create economies of scale in the use of LNG.

The Action is a continuation of the COSTA II –East (Poseidon-Med, not part of the GAINN-IT initiative) and it is a part of the Global Project aiming to take all the necessary steps towards adoption of LNG “as marine fuel” in Eastern Mediterranean Sea while making Greece an international marine bunkering and distribution hub for LNG in South Eastern Europe. The Action will establish all appropriate facilities in the area. Starting from the LNG import terminal of Revithoussa, the Port of Piraeus and the entire infrastructure at the core ports of Greece and Cyprus, the NAPA ports of Italy, Croatia, and Slovenia. The Global Project takes into consideration the existing sources of NG in Middle East and Africa as the major gas suppliers but also the exceptional potential of the EU Member States of Greece, Cyprus to be NG producers in the near future.

2.3.4 *GAINN4MED Action*

The GAINN4MED Action is a Project selected for funding under the 2016 CEF Transport Multi-Annual Call within the Innovation Priority. The Action started in 2017 and is currently ongoing, being coordinated by the Italian Ministry of Infrastructure and Transport.

The general objective of the GAINN4MED Action is to factually contribute to the implementation of the AFI Directive and related Italian National Policy Framework ensuring a sustainable and efficient multi-modal

transport system in the long run, with particular regard to LNG innovative solutions deployment along Core Corridors of the TEN-T network. In doing so, it triggers Step 3 “start-up” of the GAINN_IT Initiative.

To address such an objective, the GAINN4MED Action focuses on road transport, being the most mature sector for LNG deployment, able to act as a driving force for the development of the whole national and European LNG supply chain.

Therefore, the Action faces the most urgent need of deploying a minimum natural gas network in those areas that present a lower or zero degree of coverage, such as central and southern Italy, and of ensuring the cross-border continuity of road transport along the mayor alpine passes.

The Action consists of a study with pilot deployment of LNG and CNG solutions in Italy to contribute to the decarbonisation of road transport through transition to innovative, environmental and sustainable technologies. A network of L-CNG filling stations will be established overcoming the lack of infrastructure, in line with National Policy Framework requirements, along the Core Corridors of the TEN-T Network.

More in detail, the heart of the Action is the pilot deployment in a real-life context of a starting network of 6 L-CNG filling stations, supported by ISO-containers as mobile infrastructure, together with a starting fleet of HDVs as mobile equipment ensuring an effective start-up of the network itself. The definition of a sustainable Bio-LNG supply chain model and the establishment of proper training and skills building will widen the scope of the Action, strengthening its added value and enhancing the sustainability of the results.

The coordination and alignment with Parental Actions of the GAINN_IT Global Project will deliver a strong clustering effect and complementarity of the results, supporting both Italian National Authorities and the EC in the full deployment of alternative fuels infrastructure.

The Action contributes in fact to GAINN_IT’s aim to trigger investments in sustainable transport and support the deployment of a continued network of alternative fuels infrastructure, with particular reference to LNG, at national and European level.

The specific objectives of the GAINN4MED Action can be summarized as follows:

1. Remove major bottlenecks in supplying LNG to road transport in Italy by the progressive deployment of L-CNG stations along the Core network;
2. Deploy a series of innovative LNG-based solutions and mobile infrastructure for the development of a logistic chain for the supply, distribution and use of LNG. This will be met by:
 - Establishing a safe and efficient multimodal, ISO-container-based supply chain supporting the L-CNG stations;

- Fostering an appropriate demand for LNG promoting the build up of a fleet of LNG heavy duty vehicles.
3. Prepare a Business Plan based on the real life trials of the LNG-based solutions including C-LNG stations, mobile supply chain and HDV fleet. This will be achieved by the collection of operational data during the trials in real life context within the Action;
 4. Promote the use of Bio-LNG. To achieve this objective, guidelines and models for the use of Bio-LNG will be developed and real life tests will be made according to the results of the model and the existent possible Bio-LNG sources;
 5. Develop skills for the operation/use of LNG as fuel for land-based transport. All personnel necessary to properly operate and/or use the pilots developed in this Action will be trained accordingly.

2.3.5 GAINN4MID Action

The GAINN4MID (GAINN for Mobile Infrastructure Deployment) Action has been selected for funding under the 2017 CEF Blending Call, is currently ongoing being coordinated by Consorzio 906 (Italy) and follows the Innovation pipeline of the GAINN_IT Initiative.

The Action thus benefits from the “study”, “prototyping” and “start-up” phases implemented by the GAINN_IT Parental Actions mentioned above (namely GAINN4MOS, GAINN4CORE, Poseidon Med II and GAINN4MED). GAINN4MID contributes to the most urgent needs of the GAINN_IT Global Project and most importantly triggers its Step 4 ROLL-OUT by providing both land and maritime mobile and fixed LNG infrastructure.

It aims to contribute to the implementation of the AFI Directive and the related Italian National Policy Framework to ensure a sustainable and efficient multi-modal transport system in the long run, with a focus on innovative Liquefied Natural Gas (LNG) solutions.

The Action includes the deployment of a network of 4 Liquefied- Compressed Natural Gas (L-CNG) filling stations in Italy supported by ISO-containers logistics.

Additionally, the Project foresees the realization of the multi-modal LNG terminal in Santa Giusta port, near Oristano, suitable to receive, store and supply LNG primarily to transport users.

On the land-supply side, the terminal will be capable to load two LNG trucks at the time, as well as distributing LNG inward to a variety of end users. The terminal will also be able to load LNG on a bunkering vessel, for supplying LNG fuelled ships and other storage and distribution plants in the West Med.



Figure 27 – Rendering of the LNG small scale terminal in Santa Giusta (Oristano).



Figure 28 – Gas&Heat type c tanks delivery

Being the only LNG gateway in the area, the terminal will allow also the supply of LNG to core nodes on the island (e.g. Cagliari) while also potentially serving the central and southern Italy mainland, thus enhancing the sustainability of the transport sector on a wider scale. The terminal will have a total overall capacity between 120.000 and 180.000 tons/year of LNG and will operate in strong synergy with another key asset realized within the Action.

In fact, maybe the most innovative aspect of the GAINN4MID Project is the build up of a mobile LNG distribution system in the West Mediterranean and Tyrrhenian and Ligurian Sea able to provide flexible and demand-driven LNG services through the construction of a 7.500 m³ LNG Bunker Vessel (LBV) devoted to serve maritime ports and LNG Small Scale Systems, pursued by Stolt Nielsen.

The LBV is designed to be able to both transport LNG to satellite terminals and storages and provide direct ship-to-ship bunkering services to LNG fuelled ships in the Mediterranean Sea. In this way the LBV acts as

fundamental connection element between the land and maritime transport and supply chain.

The LBV will be a double side, single bottom, single decked, single screw tanker for the carriage and bunkering of Liquefied Natural Gas, with dual fuel LNG mechanical propulsion plants and independent IMO Type C steel cargo tanks.

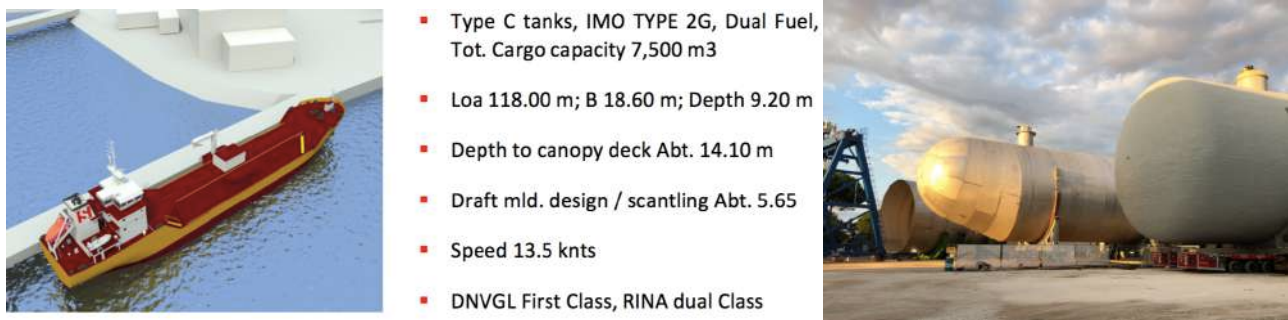


Figure 29 – Rendering (left), main data (center) and picture of the containment tanks at Gas&Heat's facility (right) .of the LBV under construction within the GAINN4MID Action

The two LNG IMO type C tanks, the largest of their kind ever built in Europe for an LNG bunkering vessel, will be provided by Gas & Heat Spa as Stolt-Nielsen Gas' selected supplier for manufacturing and testing the LNG tanks and systems.

GAINN4MID will be implemented along the Scandinavian- Mediterranean, Baltic-Adriatic and Mediterranean Core Network corridors.

2.3.6 GAINN4SEA Action

The GAINN4SEA Action (GAINN for South Europe mAritime LNG rollout) selected for funding in the Priority "Pre-identified projects on the Core Network Corridors", "Maritime ports" sub-priority of the 2017 CEF Blending Call, with an investment of over 140 million Euro, entails only infrastructure works in the ports of Venice and Livorno under the coordination of Consorzio 906 (Italy) and the participation of industrial actors such as the newly established Venice LNG company (born from the union between Decal Depositi Costieri Calliope SpA and San Marco Petroli SpA) , Costiero Gas Livorno SpA, the newly created Neri Vulcangas Investimenti Srl (purpose company created by Neri Group and Vulcangas), supported by the Port Authorities of Venice and Livorno.

The GAINN4SEA – GAINN for South Europe mAritime LNG roll-out Action aims at overcoming this main cross-border bottleneck.

The general objective of the Action is to answer to the widespread need in terms of addressing cross-border bottleneck at Priority Corridors level and to factually face the most urgent need of overcoming the chicken-egg situation that hampers the successful implementation of alternative fuels in transport as set by AFID (Directive 2014/94/EU) that aims “to enable LNG vessels to circulate throughout the TEN-T Core Network by 31 December 2025” and to face the new Sulphur limits in EU waters by 2020 regulated by Directive 2016/802/EU and in line with the new global limits imposed by IMO MARPOL Annex VI.

The planned interventions within the Action, that started in 2017 and is ongoing at the time of writing, can be summarized as follows:

1. the 32,000 m³ multi-modal storage and distribution terminal built by Venice LNG, with the involvement of the Northern Adriatic Sea Port Authority, in the port of Venice;



Figure 30 – Rendering of the designed multi-modal LNG terminal in Venice (Decal terminal) within the GAINN4SEA Action

The terminal will consist of the following elements:

- 3 LNG storage tanks (1 full containment atmospheric tank of 30.000 m³ and 2 bullet tanks of 1.000 m³) and related equipment for a total capacity of 32.000 m³, ensuring a maximum LNG turnover of 900.000 m³/year of LNG;
- 1 berth able to receive for 30.000 m³ bunkering vessels;
- 1 berth for barges of about 1000 to 3.000 m³ (to be realized on the same “Decal 1” quay, slightly east of the existing loading/unloading structure);
- 3 loading bays dedicated to LNG tank trucks;
- 3 loading bays dedicated to modular rail tanks such as LNG ISO-containers;
- 1 flare system installed for safety purposes;

- 1 Boil Off Gas management system
2. the 9,000 m³ multi-modal and modular LNG storage and distribution terminal built by Costiero Livorno and Neri Vulcangas Investimenti S.r.l, with the involvement of the Port Authority Authority of the Northern Tyrrhenian Sea, in the port of Livorno.

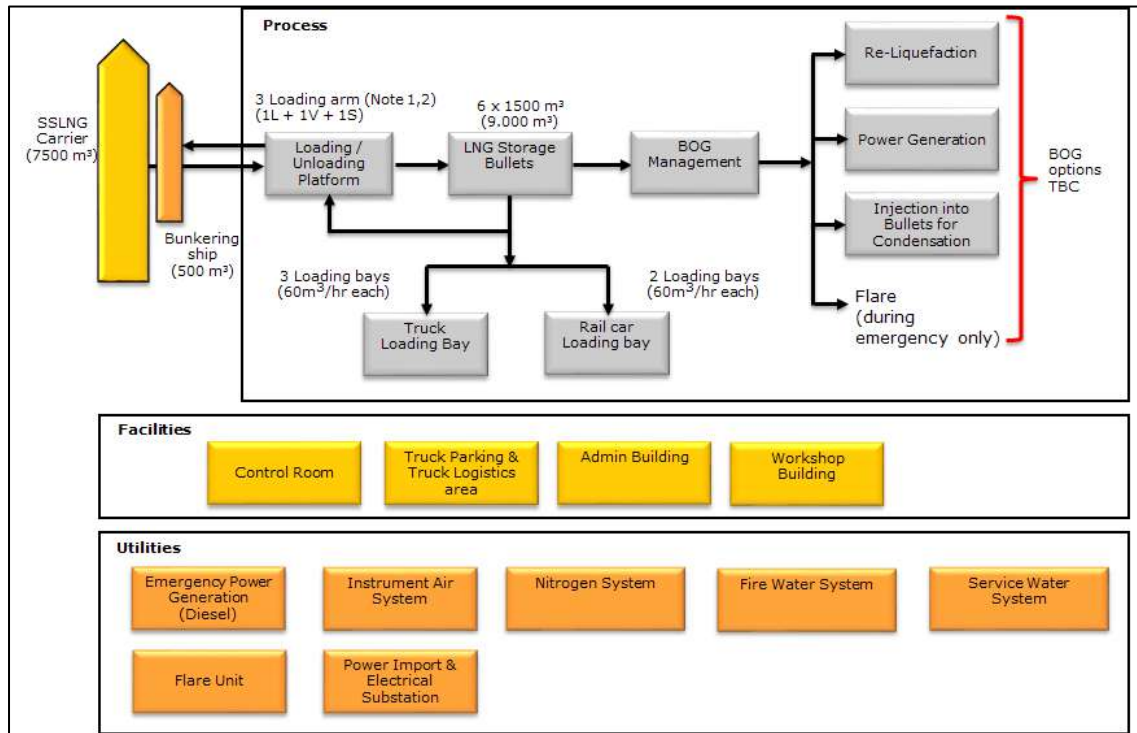


Figure 31 – Block Flow Diagram of the designed multi-modal LNG terminal in Livorno within the GAINN4SEA Action

- 6 horizontal low pressure cryogenic tanks (and related equipment) of 1.500 m³ each for a total capacity of 9.000 m³, ensuring a maximum LNG turnover of 170.000 m³/year of LNG;
- 1 berth dedicated to both loading and unloading small-medium sized LNG bunkering ships;
- 3 loading bays dedicated to LNG tank trucks;
- 3 loading bays dedicated to modular rail tanks such as LNG ISO-containers;
- 1 Boil Off Gas management system;
- 1 flare system installed for safety purposes;

The two infrastructure will therefore act as LNG gateway in the Thyrrhenian- Ligurian and Adriatic-Ionic Grid and in the relevant Core Corridors and in the Mediterranean, for both land (road and rail) and maritime transport. The LNG land distribution will be provided via trucks, ISO containers and rail services, through

dedicated rail and road loading bays, while the ships bunkering will be ensured by dedicated quays. In addition, in the Port of Venice the inland navigation supply will be possible via the neighbouring inland waterways networks (e.g. to Mantova and Chioggia).

2.3.7 The way ahead

Regarding the future steps to be undertaken by the GAINN-IT Initiative making use of the co-financing available under the CEF, a lot will depend upon the availability of budget of the upcoming call for proposals. The current 2019 CEF call for proposals concerns only comprehensive ports, cross-border sections of the global network and the reduction of railway noise.

Yet, a work program aimed at launching a blending facility scheduled for June 2019, having that of alternative fuels among its top priorities is under evaluation.

A further significant call is instead expected for the beginning of 2020 with the resources returned by the mid term review to cover, as usual, the needs of the transition to the new 2021-2027 program.

Regarding the new CEF Regulation 2021-2027, the EU Council adopted in December last year a partial general approach¹⁵ which, as regards the relevant transport part, represents a Council orientation on all the conditions of the Regulation, except for those related to the financial endowment, the Cohesion countries and the Brexit effects that are dealt with on other negotiation tables.

The European Parliament voted in plenary on December¹⁶ triggering the preparatory work in the Council, which seeks to find a compromise between the Commission's text, Parliament's amendments and the partial orientation of the Council.

3 La Spezia Port case study

3.1 Port's overview

Thanks to its strategic geographic location, La Spezia is one of the most important commercial ports in the Mediterranean sea and is the second largest Italian container port for direct access to the production and

¹⁵ <http://data.consilium.europa.eu/doc/document/ST-15146-2018-INIT/en/pdf>

¹⁶ [Http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+TA+P8-TA-2018-0517+0+DOC+PDF+V0//EN](http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+TA+P8-TA-2018-0517+0+DOC+PDF+V0//EN)

consumption markets in northern Italy, with weekly connections to all the continents of the world. La Spezia is part of a large port cluster embracing other important sea economy sectors, such as shipbuilding, yachting, tourism, aquaculture and represents one of the most significant economic reality of the Ligurian territory, with about 8,500 employees.

The port, situated within a harbour of 150 acres protected by a breakwater, can operate all year round by any weather and sea conditions while pilotage, towage and mooring services allow full operation for 24 hours a day, 365 days a year. It has more than 5 km of quays, 575,000 square meters port areas, 17 km railway tracks and more than 15,000 square meters covered warehouses. Fifty shipping\ lines, link it to over 200 ports all over the world.

The port of La Spezia's performances reach the ones of the major Far East ports, due to an utilization percentage which is among the highest in the world, with over 4 TEU handled per square meters.

As reported in the Regulation 1315/2013 the port has been included within the strategic node of the TEN-T core network, the trans-European transport central network, as core port of the Scandinavian - Mediterranean corridor.

Today, the port is able to receive ships up to 14,000 TEU and ongoing dredging works will allow to accommodate ships up to 16,000 TEU. The port has excellent railway and highway connections, including a tunnel, linking the port areas directly to the highway network and a railway station. 35% of container traffic is handled by rail, which is a top percentage in Europe, aiming to reach 50% thanks to a new rail infrastructure (that allows train composition up to 650 meters long) in according to the Port Master Plan. Linked to the North Italian intermodal hub, La Spezia serves industrial domestic market and reaches Central and Southern Europe destinations via the main rail freight corridors.

In order to improve intermodal services and increase rail transport, a new company has been established, "La Spezia Railways Shunting": this will make train operations in the port more easier, referring to a single entity coordinating operations and rail services within the port of La Spezia and the area of S. Stefano di Magra.

The distribution to the main inland markets is possible through the Tyrrhenian – Brenner Corridor for Emilia Romagna and Veneto, the railway line La Spezia - Genoa - Milan (Rhine Alpine Corridor) for Lombardy and Piedmont, and the line La Spezia - Pisa - Florence - Bologna for Tuscany and Emilia Romagna.

Some features of the port of La Spezia will have to be taken into account by the Italian policy framework on alternative fuels:

- Availability of large industrial areas suitable for hosting LNG coastal deposits;

- Existence close to the port of terminals for handling and storage of oil, natural gas and liquid chemical cargo;
- Existence in the port of the Panigaglia LNG Terminal, owned and managed by GNL Italia, allowing the regasification of liquefied natural gas imported by shippers
- Important ongoing investments for the enhancement of the port;
- Constant growth of the maritime traffic in the last years, also thanks to the connection between TEN-T Corridors and Motorways of the Sea connections;
- La Spezia is a strategic port of the Scandinavian - Mediterranean corridor in the implementation of alternative fuels; as reported in the final report “Scandinavian-Mediterranean Core Network Corridor Study”, “..The Port of La Spezia participated in the EU COSTA project. La Spezia, for example, is planning to provide LNG facilities for maritime side (vessel bunkering, tug bunkering), port operations (use of LNG for cranes, reach stackers or other operational equipment) and land side (use of LNG for train shunting, shuttle trains to inland terminal and LNG trucks)...”

LNG strategy of La Spezia Port is shown in the activity of COSTA II - POSEIDON MED project, which objective is to define future scenarios about the implementation of a transport chain based on LNG.

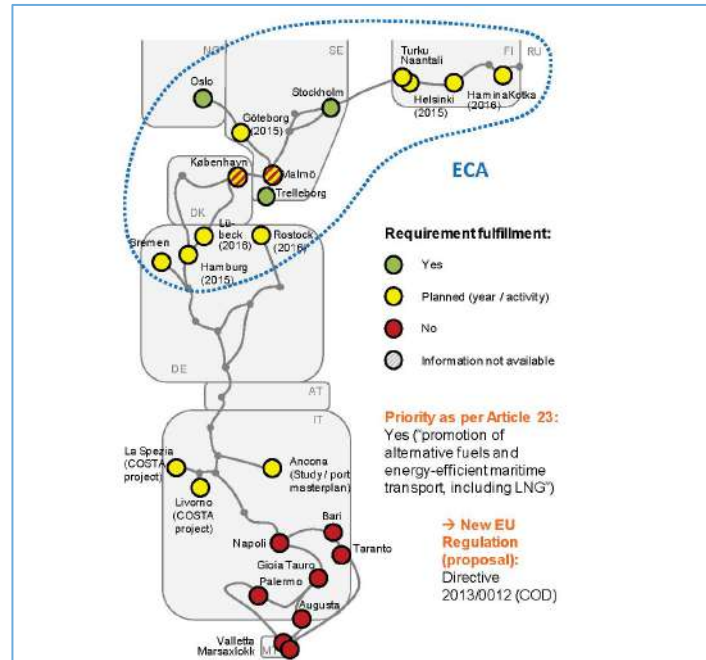


Figure 32 – Analysis of requirement “LNG bunkering facilities” for ScanMed Ports

Source: Scandinavian-Mediterranean Corridor Final Report – 2016

According to the Regulation 1315/2013 on Union Guidelines for the development of the trans-European transport network, the port of La Spezia is a Core port in the Scandinavian - Mediterranean Corridor and it shall respect the Art. 23 concerning the priorities for maritime infrastructure development.

In this respect, at page 226 of the final report *“Scandinavian-Mediterranean Core Network Corridor Study”*, several ports show activities regarding the development and installation of LNG bunkering facilities; regarding La Spezia Port, we can read that *“...La Spezia, for example, is planning to provide LNG facilities for maritime side (vessel bunkering, tug bunkering), port operations (use of LNG for cranes, reach stackers or other operational equipment) and land side (use of LNG for train shunting, shuttle trains to inland terminal and LNG trucks).”*

For this reason La Spezia is a strategic port of the Scandinavian - Mediterranean corridor in the implementation of alternative fuels in transport.

The distribution to the main inland markets is possible through the Tyrrhenian – Brenner Corridor for Emilia Romagna and Veneto, the railway line La Spezia - Genoa - Milan (Rhine Alpin Corridor) for Lombardy and Piedmont, and the line La Spezia - Pisa - Florence - Bologna for Tuscany and Emilia Romagna.

3.2 The Panigaglia LNG terminal

In depth analysis of this key asset for the Port of La Spezia and, more in general, for the Tyrrhenian-Ligurian LNG Grid as a whole, was realized by the author during the *On the MoS Way Network (OTMW-N)* Project, a Common Learning Action coordinated by the University of Strathclyde and co-financed by the European Commission through its Innovation and Network Executive Agency (INEA) under the Marco Polo Programme.

Within Project's Activity 2 *“Cross fertilization on site dedicated visits related to LNG best practice”* 5 site visits aiming at visit places and interview professional in order to gather concrete knowledge on some of the core elements of the LNG supply chain were organized by the University of Genoa.

3.2.1 Terminal overview and location

The Panigaglia plant owned by GNL Italia S.p.A. is located in the town of Fezzano di Porto Venere (SP), within the Gulf of La Spezia.

It plays a strategic role in providing a supply of natural gas which is complementary to the entry points of the gas pipeline network and responds to the energy demands of the country.



Figure 33 – Location of the Panigaglia Plant within the Gulf of La Spezia

Built between 1967 and 1970, the Panigaglia plant was the first LNG reception and regasification terminal to be built in Italy.

Between 1990 and 1996 there was a significant landscape and environmental rehabilitation project carried out by the School of Architecture and Landscape of Genoa which facilitated the location of the plant in its surroundings.

Another set of upgrade works was carried out between 1995 and 1997 and saw the modification of the two LNG storage tanks, transforming them from single to double containment tanks.



Figure 34 – View of the Panigaglia LNG terminal following last upgrading. GNL Italia company information

In 2007, GNL Italia had presented a project for the modernization and upgrading of the LNG plant in Panigaglia. The project consists in:

- an increase of the regasification capacity to 8 billion m³ per year from the current capacity of 3.5 billion m³ per year;
- an average daily capacity of regasification of 38,000 m³;
- realisation of a new pumping system;
- adjustment of the vaporization system through the substitution of the existing vaporizers with 6 new ones;

- renovation of the LNG storage tanks with an increase of the tank capacity up to 240,000 m³ (currently 100,000 m³);
- modification of the jetty with increase in the reception capacity for LNG carriers with capacity of 145,000 m³.

In 2009 the project received favourable opinion of environmental compatibility by the Ministry of Environment.

In the annual financial relations of 2011 and 2012, GNL Italia confirmed the project “in the medium term” in order to increase the regasification capacity to 8 billion m³ per year, but in the following relations (2013, 2014 and 2015) there’s no explicit reference to the project. At the same time, no particular advance in the realization process emerges from a recognition of the online press.

The facility now consists of the following elements:

- The Plant itself, which occupies an area of approximately 45,000 m², consisting mainly of two LNG storage tanks, vaporization plants, the pier for LNG carriers to berth and auxiliary systems;
- A number of buildings used primarily as offices, maintenance workshops with the
- Relevant equipment and warehouses;
- Green areas established following the first restructuring phase, in order to comply with environmental standards;
- A woodland area, surrounding the facility.

3.2.2 Plant’s process and technical features

When it comes to process description, the Panigaglia plant, which occupies a total area of 45,000 square metres, is made up of seven areas: receiving, storage, regasification, vapour recovery, final gas correction, ancillary systems and control and safety systems.

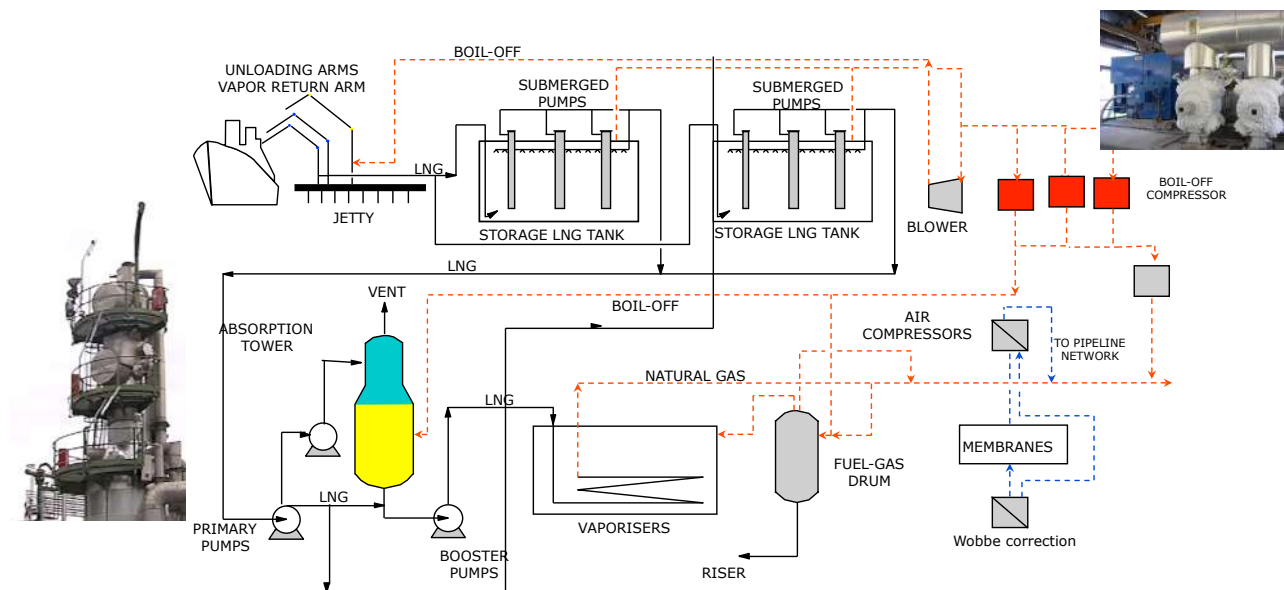


Figure 35 – The processes at the Panigaglia Regasification Terminal. GNL Italia company information

LNG receiving

From the far exporting countries, the LNG is transported by sea by specific, high technology tankers with safety systems and environmental protection quality standards which are among the highest in the world. The receiving area of the Panigaglia plant consists of a berthing area for the LNG carriers, three unloading arms and a transfer line to the tanks. The load capacity of the LNG carriers varies from 25000 cubic meters up to 65,000/70,000 cubic metres, thanks to the 500-metre long pier.

The sea surrounding the head of the pier is about 10 metres deep and is used exclusively for the manoeuvring and berthing of LNG carriers.

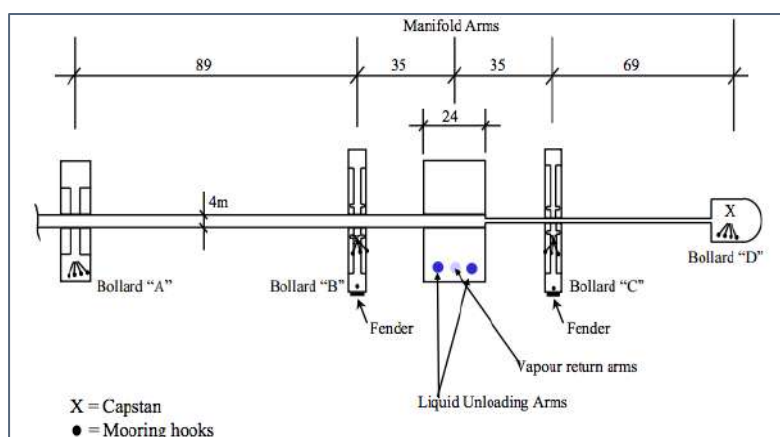


Figure 36 – Layout scheme of the mooring bollards at the Panigaglia plant's pier. GNL Italia company information

The pier has four mooring bollards, each of which is equipped with quick release mooring hooks, and two fenders to protect the ship, which are equidistant from the unloading arms and have a centre to centre distance of approximately 70 metres.

The LNG unloading system at the pier is made up by 3 arms:

- ✓ 2 liquid arms for LNG (diameter 12", flow rate 3000 m³/h each with a total discharge capacity of 4000 m³/h);
- ✓ The central arm is used for vapours return to the ship (diameter 8", flow rate 12.000 Sm³/h).



Figure 37 – Detail of the unloading arms at the Panigaglia plant's pier. GNL Italia company information

All the arms are equipped with a quick release system called PERC (Powered Emergency Release Collar).



Figure 38 – View of the pier at the Panigaglia plant. GNL Italia company information

The LNG is unloaded from ship carriers and sent through a pipeline which crosses the approximately 500 metre wide wharf. The transfer line is usually kept cold and filled with LNG. The pipe's diameter is roughly 24 inches. Through the pipeline, LNG flows to the storage tanks.

LNG storage

LNG is loaded to and unloaded from the bottom by pipes entering from top of the storage tanks. In particular, to avoid stratification, the loading pipes are equipped with jet nozzles.

The LNG storage area consists of 2 cylindrical tanks (with a capacity of 50.000 m³ each). Each tank is about 30 m high with a diameter of 53 m.

The LNG is stored in double containment tanks: the inner container is designed to contain the LNG, while the outer one supports and protects the insulating material placed in the cavity between the two. The roof the external containment is made by carbon steel and as a consequence in the event of damage to or breach of the inner container only the liquid could be safely contained from the external storage tanks but not the vapor (double containment)

- ✓ Internal tank is made of 9% Nickel steel;
- ✓ External tank is concrete;
- ✓ Insulation is perlite;
- ✓ Each tank is located inside a containment basin.

The liquified natural gas is stored at a temperature of approximately -160°C and at a pressure which is slightly higher than atmospheric pressure.

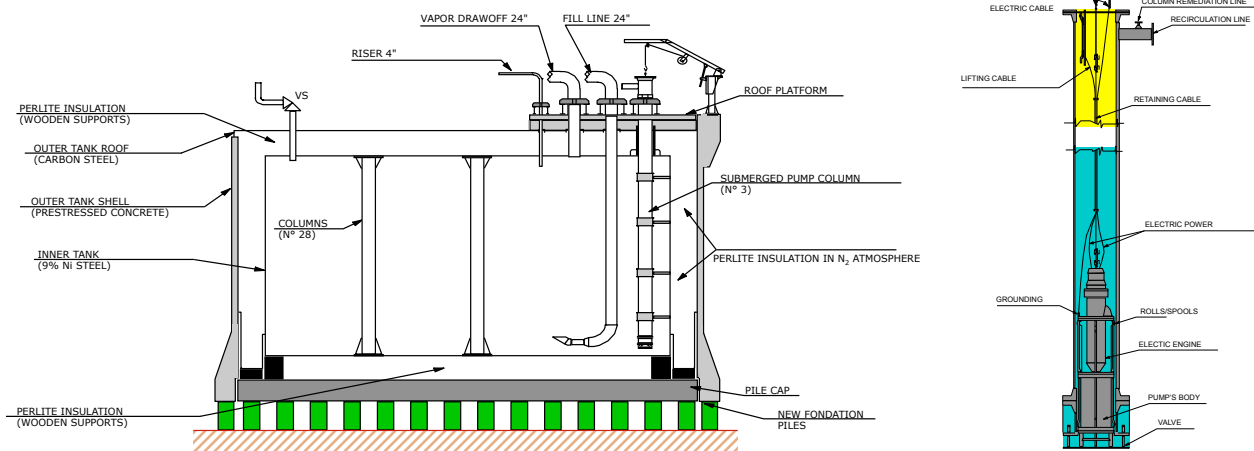


Figure 39 – Layout scheme of the containment tank and detail of the submerged pump at the Panigaglia plant. GNL Italia company information

Inside each of the two tanks are placed three submerged pumps for the movement of LNG:

- 2 centrifugal pumps (2 for each tank and each one with a nominal capacity of $500\text{ m}^3/\text{h}$ and a send out pressure of about 3 bar)
- 1 submerged pump for recycling – capacity: $170\text{ m}^3/\text{h}$ for each tank.

Pumps are lubricated by the LNG itself

Regasification area

From the storage tanks, LNG flows to the regasification area.

In this area we can find:

- ✓ 2 sets of High pressure pumps for the movement and pressurisation of the LNG
- ✓ the submerged combustion vaporiser.



P101 pumps
(primary - 25 bars)



P104 pumps
(booster – 80 bars)

Figure 40 – High pressure pumps at the Panigaglia plant. GNL Italia company information

The liquefied natural gas is drawn from the tanks and sent through the pipeline to the vaporisation units.

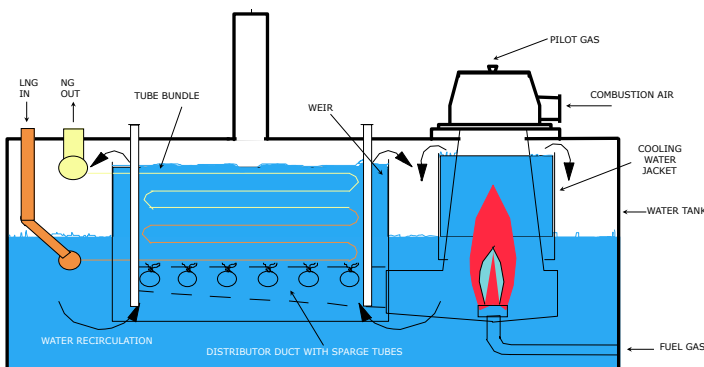


Figure 41 – Vaporizers at the Panigaglia plant: layout scheme and tube bundle. GNL Italia company information

The vaporizer use the heat produced by the combustion of the gas and heat the LNG to a temperature close to that of the air, thus turning it to its gaseous state.

BOG recovery

The plant recently changed the boil off recovery and the plant automation system, in order to further

improve its performance and safety.



Figure 42 – BOG recovery system at the Panigaglia plant. GNL Italia company information

- The boil off system is made of 3 compressors (send out pressure 25 bars) in order to send the BOG inside the recondenser where it turns back to the liquid phase
- 1 HP compressor able to send the gas directly to the external grid

For the recovery of boil-off gas, three compressors are used to transport the gas from the tank to an absorption column. In the absorption column the gas is condensed and goes back into the production cycle.

The terminal is equipped with a blower able to send boil-off vapours to the ship ($12.000 \text{ Sm}^3/\text{h}$) in order to control pressure inside the ship tanks.

Gas correction, ballasting system and wobbe index reduction

The correction of the final gas is intended to maintain the quality specifications of the gas inserted into the transmission network to ensure the interchangeable nature of the regasified LNG in compliance with the quality specifications required by the transmission network.



Figure 43 – Gas correction unit at the Panigaglia plant. GNL Italia company information

If necessary the correction of the gas is made by adjusting the «Wobbe Index» (Gross Calorific Value divided by the square root of the relative density of the gas with the air): if the value of this parameter is excessive, it simply adds air or air enriched with nitrogen, with the aid of suitable compressor batteries.

The auxiliary system area includes all support operations for the main process, such as an electrical substation, the fire fighting system, heat dispersion system and the metering station to measure the quality and quantity of gas introduced onto the network.

Finally the natural gas is then injected into the transmission network which transports it to end users.

Control and safety

The control and safety system is extremely important: the regasification plant is controlled and operated remotely by the automated Centralised Control Room.

The system is divided into two subsystems:

- the distributed control system (DCS), which acquires, processes and adjusts process parameters and supervises the plant;
- the programmable electronic system (PES), which governs the start-up, stopping and blocking of the equipment sequences as well as activating the automatic safety procedures in the event of an emergency.

In addition, internal and external security is guaranteed by a specific unit which is manned 24 hours a day, 365 days a year.

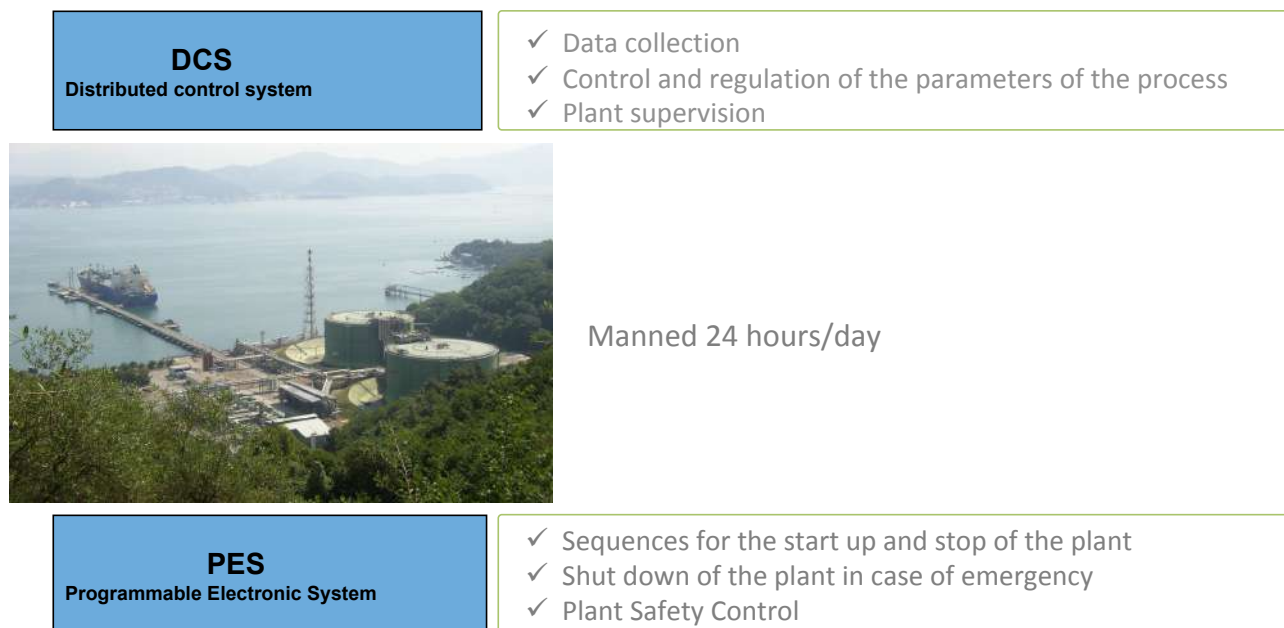


Figure 44 – Overview of the control scheme concept at the Panigaglia plant. Elaboration on GNL Italia company information

3.2.3 Logistic constraints

A short consideration must also be made regarding the local road connection in the area which seems to present some criticalities for truck transport.

The area in which the LNG Panigaglia regasification terminal is based, is served only by a single road, the provincial road n.530 (known as the ancient Napoleonic), which passes a few tens of meters from the LNG storage tanks and from the dock. The road is known to be narrow and winding and, above all, landlocked. Besides following an irregular path along the coast, the road terminates in Portovenere (8 km beyond Panigaglia) and has no viable alternatives for a truck, so that in case of interruption of the road, supplying of LNG to La Spezia might be subjected to delay. It is frequented by locals as well as by numerous coaches and tourist cars as well as by military vehicles serving the base of Varignano. Furthermore this road is often affected by accidents that, as also recently happened, may isolate the Municipality of Porto Venere.

A series of barges capable of transporting LNG tanker trucks or preferably ISO-containersd from Panigaglia to an area within the port perimeter is something there has been investigating on. The feasibility study developed by D'Appollonia in 2016 has in fact also envisaged the use of this type of vehicle to avoid

engaging the only existing road with dozens of tanks a day: something that, according to several opinions, would give the final blow to the already precarious balance of the road to Porto Venere.

It is then to be noted that besides the LNG that may be destined to serve users in the Port of La Spezia, another share of traffic may in future be represented by the tankers loaded with liquid gas destined for other inland Italian storage and distribution centers. These will have to reach the highway entrance along the Napoleonic road described above up to the city of La Spezia and then cross the whole city passing through densely populated neighborhoods. Alternatively, such tankers may be loaded onto barges and transported by sea to the nearest point to the highway, thus covering a route perpendicular to that of all ships and boats that daily cross the Gulf.

Finally, it is also notable that according to the External Emergency Plan¹⁷ drawn up by the plant manager, sections of this road fall within the damage zones 2 and 3, where serious effects are possible for people due to "blow fire" and "tank fire" events.

In the Plan itself, it is specified that the main access by land takes place from the north side through a stretch of dual-way private road that, coming off the SP 530, leads directly to the entrance of the plant. In case of need, there is the possibility of accessing the south side of the plant belt using the private road that originates from the SP 530 at Punta Pezzino and descends on the embankment in a northerly direction allowing you to get to the back of the plant. Should the emergency require it, the gate lock can be forced by the rescue / fire fighting units to deal with the emergency itself. These nodal points identified above (nearby a specific traffic light system was activated by GNL Italia to block traffic in the event of a major accident) will be those in which the police, deputed to the delimitation operations of the area and to regulating accesses, will carry out operations of diversion or impediment of traffic, through the use of checkpoints, in order to prohibit the flow of traffic in the area and facilitate the timeliness of interventions, also in relation to the evolution of the event.

Being understood the above constraints, it is still unclear, at the best of author's knowledge, whether the opportunity of upgrading the road is being evaluated or not. In any case, the current situation poses serious constraints that shall be taken into account, thus impacting on the practicability of certain solutions when the option of supplying La Spezia port's users with LNG from Panigaglia is considered.

¹⁷ http://www.prefettura.it/FILES/AllegatiPag/1189/PEEGNLItaliaAggto23nov2017_b..pdf

3.3 Use of the Panigaglia terminal for Small Scale LNG services

3.3.1 Considerations on general LNG import terminal upgradings to provide Small Scale LNG services

As seen in the previous chapter, a “Small Scale LNG” (or SSLNG) facility is the way the LNG is administered directly in liquid form (with respect to the regasification operated in dedicated terminals and to the following introduction in gas form in the transport network).

The use of the regasification terminals to carry out, besides the basic service, also the function of storage and LNG supply depends heavily on the type of service of provision and the characteristics of the terminals. Compared to the basic service, the following additional services (MISE, 2015) are envisaged:

- LNG loading service on bunker ships, i.e. loading of ships with LNG stored in the tanks of a regasification terminal. The loaded vessels have a capacity between 500 and 30,000 m³ and can be used to supply LNG to other vessels (i.e. used as barges) or for coastal storage tanks (used therefore as shuttles ships);
- Reloading service for LNG carriers, which is the operation whereby the LNG, previously imported and stored in the tanks of a terminal, is reloaded onto tankers (with a capacity of between 30,000 and 270,000 m³) for the re-export of the product, in order to take advantage of potential business opportunities;
- Loading to road tankers (for onshore terminals only), i.e. loading of tanker trucks (with capacity between 20 and 50 m³) or ISO-containers (with capacity between 20 and 40 m³), used for transport on road, with the LNG stored in a terminal tank. The tankers and ISO-containers can be used to supply vehicles propelled by LNG or CNG (storage capacity up to about 100 m³), local storages (atmospheric pressure tanks typically of 30,000 m³ or tanks in pressure with a typical volume of about 1,000 m³) or for other types of uses that require the supply of the product liquid state (bunkers, industrial and civil uses, trains);
- Additional services (for onshore terminals only), or services that allow the supply of LNG through the use of infrastructures built in the vicinity of the terminal and directly connected to it, such as loading of bunker ships and/or road tankers by a dedicated tank connected to the terminal, or filling heavy trucks by means of a station connected directly to the terminal.

3.3.2 *Site-specific terminal upgradings*

SNAM Rete Gas, through its subsidiary group GNL Italia, controlling the LNG terminal of Panigaglia, called on March 2015 a public tender to entrust feasibility and pre-feasibility studies to provide Small Scale LNG services. Studies are now under development after the tender award in January 2016 to D'Appolonia (Rina group) and Tractebel (Engie group). No documentation or update has been diffused up to now, so the main characteristics of the project can be derived from the call document.

The tender call concerns reloading of feeder ships; loading of barges, road tankers and ISO containers; liquefaction of natural gas from pipeline; and loading of road tankers from a coastal storage installation located outside the terminal.

In particular, according to the call, SNAM would be interested to realize:

- storage tanks, transfer line, wharf;
- loading of ships, road tankers and ISO containers in the terminal, both with regasification plant active and not (with concern to boil-off gas treatment);
- loading of road tankers and ISO containers at the terminal, both with regasification plant active and not;
- liquefaction of natural gas from pipeline and loading of the terminal tanks;
- outside of terminal, coastal storage installation, stocked up by feeder ship, in order to load road tankers and ISO containers.

Studies are now under development after the tender award in January 2016 to D'Appolonia (Rina group) and Tractebel (Engie group). No documentation or update has been diffused up to now.

3.4 *Potential international sources of LNG supply*

In order to identify potential sources of supply for La Spezia, a three step procedure was followed. In the first step facilities with operational or ready-to-start services (facilities under construction or planned with start-up year in 2016-2017) were selected from the GIE database.

In the second step, sea and road distances to/from La Spezia were calculated¹⁸.

In the third step, potential sources of supply were selected by identifying the nearest ports by ship or road, imposing that only one port for each nation was selected.

Selected ports are Marseille – Fos-sur-Mer (France), Barcelona (Spain), Zeebrugge (Belgium) and Rotterdam (Netherlands). Fos-sur-Mer is the nearest port to La Spezia by sea, followed by Barcelona. Fos-sur-Mer and Barcelona are also, respectively, the nearest ports by road, followed by Zeebrugge and Rotterdam.

Marseille and Barcelona were selected for being the nearest ports by sea and by road. Other Spanish ports were not included because, given the methodology used, cost estimates would have been analogous and transit times superior. Other ports in the Mediterranean were not included because distances were almost the triple than from Barcelona to La Spezia.

Zeebrugge and Rotterdam were chosen for being the nearest by road after Marseille and Barcelona. The inclusion of Zeebrugge and Rotterdam also results useful allowing to test costs and transit times for a railway option (transport of an ISO Container by train) via Melzo.

18 The length in terms of kilometers for road routes was calculated via Google Maps. The length in terms of kilometers for naval routes was calculated via the calculation engine made available by EcoTransIT. The methodology behind EcoTransIT was developed by the German Institute for Energy and Environmental Research (IFEU - Institut für Energie und Umweltforschung) in Heidelberg, Rail Management Consultants GmbH (RMCon), and IVE mbH, within a research project founded under initiative of European railway companies including Trenitalia, SNCF, DB Schenker and ÖBB.

Port	Country	Distance to/from La Spezia (km)	
		Sea	Road
Fos-sur-Mer	France	485	519
Barcelona	Spain	721	958
Sagunto	Spain	984	1.275
Gijón (El Musel)	Spain	1.211	1.558
Cartagena	Spain	1.211	1.581
Huelva	Spain	1.822	2.037
Revithoussa	Greece	1.884	2.248
Sines	Portugal	2.117	2.216
Aliaga	Turkey	2.136	2.313
Alexandroupolis	Greece	2.195	1.918
Kavala	Greece	2.229	1.867
Marmara Ereglisi	Turkey	2.334	1.991
Mugardos	Spain	2.818	1.804
Bilbao	Spain	3.265	1.293
Montoir-de-Bretagne	France	3.441	1.295
Loon Plage	France	3.986	1.288
Zeebrugge	Belgium	4.072	1.249
Isle of Grain	United Kingdom	4.080	1.431
Rotterdam	Netherlands	4.184	1.266
Lysekil	Sweden	4.985	2.091
Göteborg	Sweden	5.018	1.967
Fredrikstad	Norway	5.040	2.175
Swinoujscie	Poland	5.068	1.516
Klaipeda	Lithuania	5.436	2.215
Nynashamn	Sweden	5.517	2.321
Pansio	Finland	5.788	2.618
Mosjoen	Norway	5.801	3.026
Tallinn	Finland	5.831	2.610
Gävle	Sweden	5.836	2.473
Raum	Finland	5.870	2.705
Pori	Finland	5.901	2.940
Hamina-Kotka	Finland	5.997	2.937
Tornio	Finland	6.400	3.322

Table 13 – Selection of potential port as sources of LNG supply



Figure 45 - LNG naval routes in the West Mediterranean. Source: GIE (2018)



Figure 46 - Railway connections between La Spezia and Zeebrugge/Rotterdam via Melzo. Source: Contship Italia Group company information

All the four selected terminals provide truck loading and reloading (transfer of LNG from the LNG reservoirs of the terminal into a vessel). Marseille, Barcelona and Zeebrugge provide bunker ship loading as well (loading on bunkering ships which supply to LNG-fuelled ships or LNG bunkering facilities for vessels). In Barcelona, bunker ship loading is reported under construction and ISO Container is supposed to be launched starting 2017.¹⁹

Terminal	Operational services			
	Bunkership loading	Truck loading	ISO Container loading	Reloading
Marseille	√	√	√	√
Barcelona	under construction	√	√	√
Zeebrugge	√	√	√	√
Rotterdam	√	√	√	√

Table 14 - Services in selected terminals. Source: elaboration on GIE (2018) and online recognition

3.4.1 Marseille Fos-sur-Mer

Two different installations are operational in Fos-sur-Mer. One is located in Fos Tonkin, the other in Fos Cavaou. Both installations provide bunkership loading, truck loading and vessel reloading.

Elengy operates both Fos Tonkin and Fos Cavaou (plus Montoir-de-Bretagne on the Atlantic coast). Fos Tonkin is fully owned by Elengy. Fos Cavaou is owned by Fosmax LNG, a subsidiary of Elengy, its major shareholder.

Service offered by import terminals in Fos-sur-Mer	Status	NAME of installation	Owner/Operator	Min. ship size m ³ LNG	Capacity m ³ /h LNG
Bunkership loading	operational	Fos-Tonkin LNG Terminal	Elengy	5,000	1,000
Bunkership loading	operational	Fos Cavaou LNG Terminal	Fosmax LNG	15,000	4,000
Truck loading	operational	Fos-Tonkin LNG Terminal	Elengy		1 x 100
Truck loading	operational	Fos Cavaou LNG Terminal	Fosmax LNG		not available
Reloading	operational	Fos-Tonkin LNG Terminal	Elengy	5,000	1,000
Reloading	operational	Fos Cavaou LNG Terminal	Fosmax LNG	15,000	4,000

Table 15 - Services offered by import terminals in Fos-sur-Mer. Source: elaboration on GIE (2018)

¹⁹ www.lngworldshipping.com/news/view,enags-reinvents-its-lng-import-terminals-as-logistics-hubs_44792.htm

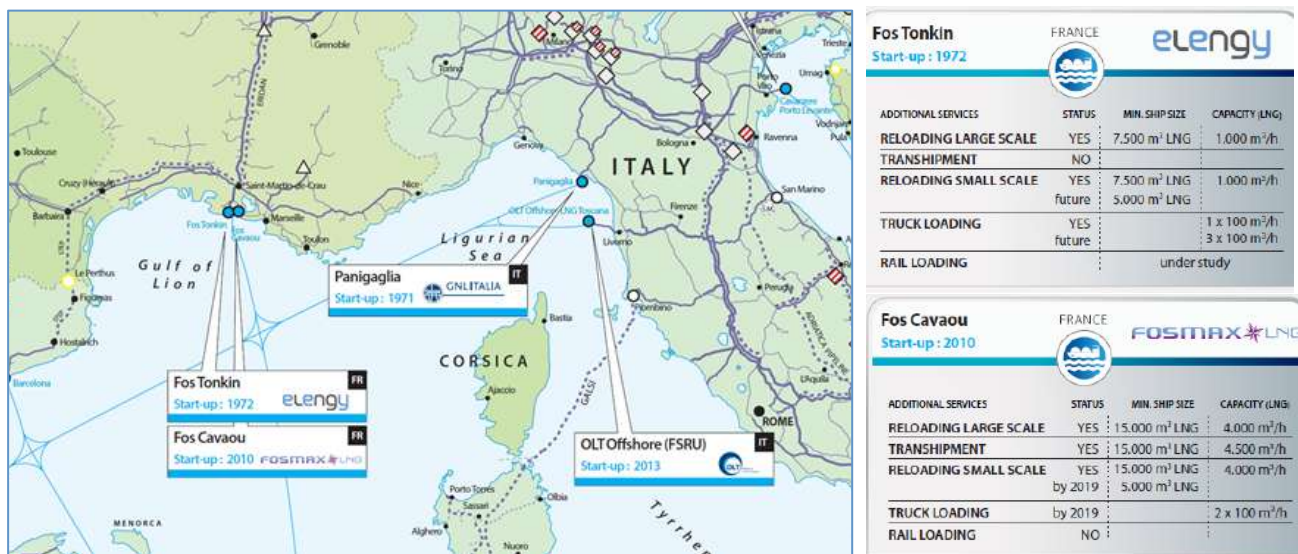


Figure 47 – Fos Tonkin and Fos Cavaou mapped LNG SS services. Elaboration on GIE (2018)

Elengy reloading rates – 4,000 m³ LNG/h at Montoir-de-Bretagne and Fos Cavaou, and 1,000 m³ LNG/h at Fos Tonkin – mean that a standard LNG tanker can be reloaded in two days (Montoir-de-Bretagne and Fos Cavaou up to Atlanticmax 175,000 m³ size) or three days (Fos Tonkin up to Medmax 75,000 m³ size).

At Fos Tonkin facility (from June 2014), Elengy offers the option of loading road tankers with LNG for transportation to its point of use. This LNG is therefore destined e.g. to supply industrial users or LNG fuel distribution stations for vehicles or ships.

Fosmax LNG, a subsidiary of Elengy in which the latter has more than a 70% stake, alongside Total through its subsidiary TGEHF (Total Gaz Electricité Holding France), owns the Fos-Cavaou Liquefied Natural Gas Terminal.

Fosmax LNG commercially exploits the regasification capacities of the terminal and led the project to construct it (studies, purchasing, construction and start-up). As regards the operation and maintenance of the site, this is entrusted to its majority shareholder, Elengy.

The Fos Cavaou LNG terminal, which is spread over 80 hectares, is situated on the Mediterranean coast, 50 km west of Marseille, in the Cavaou peninsula (Fos-sur-Mer).

Directly accessible by sea by the latest generations of very large liquefied natural gas tankers, Q-flex (around 217,000 m³) and Q-max (over 270,000 m³), it constitutes a new entry point into the French and European market. Its storage capacity is 330,000 m³ with three 110,000 m³ cryogenic storage tanks. Its

regasification capacity is 8.25 billion m³ per year, i.e. the equivalent of around a sixth of French natural gas consumption.

In detail, the Fos Cavaou installations comprises:

- A regasification capacity of 8.25 billion m³ per years;
- a combined storage capacity of 330,000 m³ of LNG (liquefied natural gas) with three identical tanks holding 110,000 m³ of LNG;
- maximum LNG ship class size: 270,000 m³;
- small scale size down to 15,000m³;
- a site of 80 hectares;
- one jetty;
- minimum sea depth along side: 15 m.

Fosmax LNG is currently looking into ways to boost this capacity in order to meet potential customer demand in 2020 and to contribute more effectively to security of natural gas supply in France and Europe. This would require the construction of one or two additional storage tanks, doubling the facility's send-out capacity to 16.5 Gm³/year. The project is scheduled to come on-stream in 2020.

The CAPMAX projects aims to boost the capacity of the current Fos Cavaou terminal, increasing its gas send-out capacity from 8.25 Gm³/year to 16.5 Gm³/year.

This 100% increase involves expanding LNG storage capacity by building one or two additional storage tanks or doubling regasification facilities.

The current terminal has enough space to accommodate these new facilities. The existing electricity supply and the transmission network provided by GRTgaz (the pipeline conveying gas away from the site) mean that no extension work is needed to double the terminal's capacity.

The piers are not expected to be altered as part of the project, as they are large enough to receive the number of gas carriers corresponding to the project's send-out capacity (16.5 Gm³), i.e. approximately 200 ships per year.

Among other things, Elengy aims at transform its terminals into LNG hubs, by developing new services: reloading of ships, transshipment, loading services for small-scale LNG tankers and road tankers.

Tanker Truck loading at Elengy facilities

Following the rapid growth of small-scale LNG market, Elengy has developed a service for loading LNG onto

road trailers and ISO containers in its terminals.

The service is available on a first booked, first served basis. The customer will need to buy LNG from one of the terminals' suppliers ahead of the loading date. Elengy needs to check and approve roadtrailers before they are filled for the first time.

Up to 4 trucks can be loaded each day in Fos Tonkin. Loading stations are fitted with flexible hoses, and Loaded LNG is weighed by weigh bridge.



Figure 48 -Tanker truck loading operation on Elengy LNG terminal. Source: Elengy company information

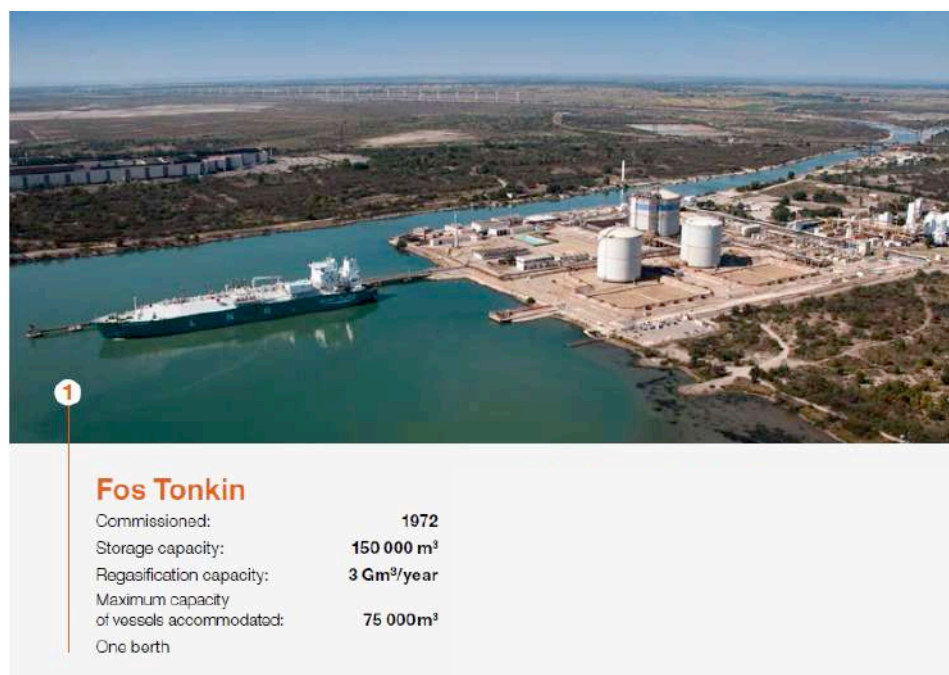


Figure 49 - Fos Tonkin aerial view and main figures. Source: Elengy

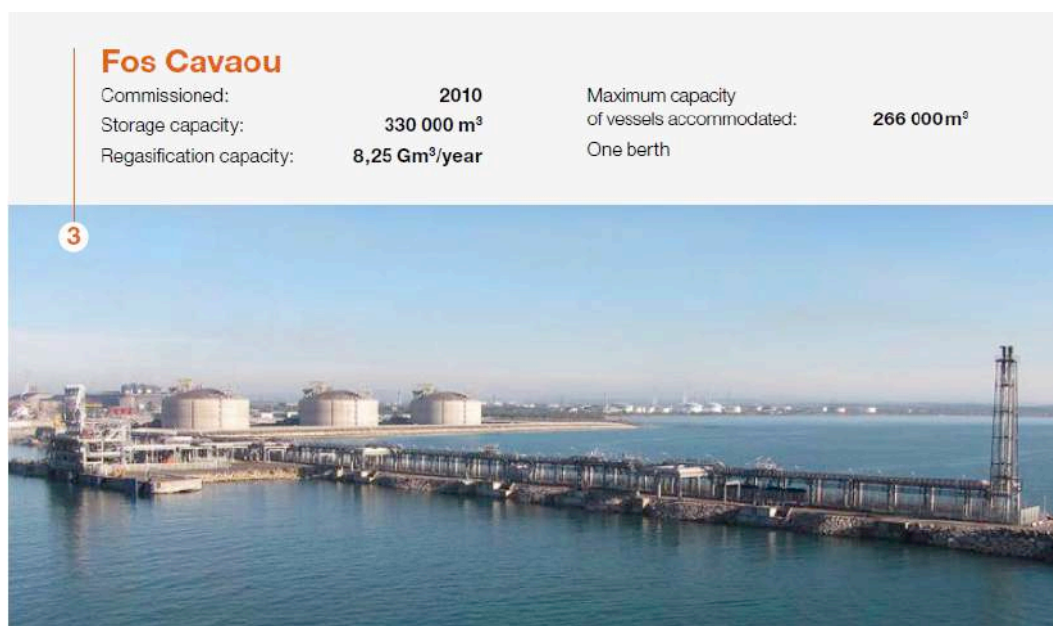


Figure 50 - Fos Cavaou aerial view and main figures. Source: Elengy company information

3.4.2 Barcelona

Barcelona LNG terminal is operated by Enagás, which has four regasification plants in Barcelona, Huelva, Cartagena and Gijón. It currently has a free float of 95%. In Barcelona, truck loading and vessel reloading are in operation.

Service offered by import terminals in <u>Barcelona</u>	Status	NAME of installation	Owner/Operator	Min. ship size m ³ LNG	Capacity m ³ /h LNG
Bunkership loading	under construction	Barcelona LNG Terminal	Enagás		
Truck loading	operational	Barcelona LNG Terminal	Enagás		3 x 91
Reloading	operational	Barcelona LNG Terminal	Enagás	2,000	3,500

Table 16 - Services offered by import terminals in Barcelona. Source: elaboration on GIE (2018).

Barcelona was the first plant to be commissioned in Spain. In operation since 1969, it is located on the flammables quay in the Port of Barcelona on the Mediterranean coast, enabling it to receive gas from countries such as Libya, Algeria, Oman and Egypt.

The Barcelona Plant includes:

- 8 tanks;


- Storage capacity of 840,000 m³ of LNG;
- Emission capacity of 1,950,000 m³ (n)/h;
- Min. / max. docking capacity of 30,000 / 266,000 m³ of LNG;
- LNG truck loading 15 GWh/day (50 trucks/day).




Barcelona

Start-up: 1969

SPAIN





ADDITIONAL SERVICES	STATUS	MIN. SHIP SIZE	CAPACITY (LNG)
RELOADING LARGE SCALE	YES	2.000 m ³ LNG	4.000 m ³ /h
TRANSHIPMENT			
RELOADING SMALL SCALE *by 2018		1.200 m ³ LNG	600 m ³ /h
TRUCK LOADING	YES		3 x 91 m ³ /h
RAIL LOADING		under study	

(*) smaller vessels under study

Figure 51 – Barcelona mapped LNG SS services. Elaboration on GIE (2018)

Enagás has three truck loading facilities at its Barcelona, Huelva and Cartagena plants, and will have another two at El Musel. This service was initially contracted to meet the needs of supply of populations or customers that were still not connected to the transmission network. Subsequently, the emergence of solar thermal electric plants has led to a greater need for this service.

Currently, Enagás's plants load an average of 140 trucks per day.

At this time, all Enagás' terminals in the country are equipped to offer logistics services that bring added value to the LNG value chain.

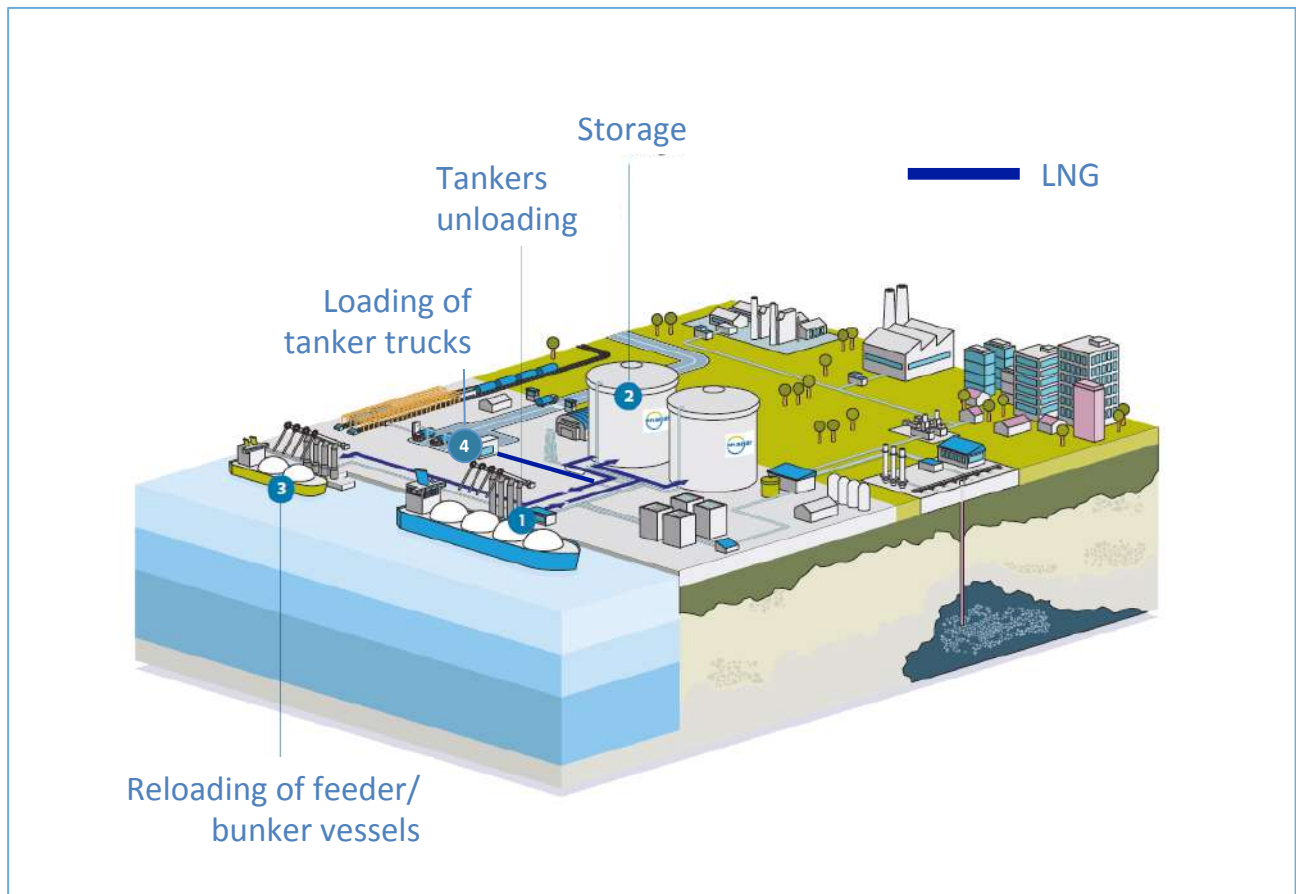


Figure 52 - Small-scale reloading service by Enagas. Elaboration on Enagas company information

3.4.3 Zeebrugge²⁰

The Zeebrugge terminal offers bunkership loading, truck loading, vessel reloading and transshipment.

Facilities are operated by Fluxys LNG, an independent company for both the natural gas transmission grid and storage infrastructure in Belgium.

²⁰ Source: Fluxys company information.

Service offered by import terminals in Zeebrugge	Status	NAME of installation	Owner/Operator	Min. ship size m ³ LNG	Capacity m ³ /h LNG
Bunkership loading	operational	Zeebrugge LNG Terminal	Fluxys LNG	7,000	5,000
Bunkership loading	under construction	Zeebrugge LNG Terminal	Fluxys LNG	2,000	5,000
Truck loading	operational	Zeebrugge LNG Terminal	Fluxys LNG		75
Reloading	operational	Zeebrugge LNG Terminal	Fluxys LNG	7,000	5,000
Reloading	under construction	Zeebrugge LNG Terminal	Fluxys LNG	2,000	5,000
Transshipment	under construction	Zeebrugge LNG Terminal	Fluxys LNG	2,000	14,000

Table 17 - Services offered by import terminals in Zeebrugge. Source: elaboration on GIE (2018)

At the Zeebrugge terminal, Fluxys Belgium sells capacity for:

- loading and unloading LNG vessels;
- storing LNG;
- regasifying LNG for transmission on the Fluxys Belgium grid.

At the facility, customers can also load LNG trucks to supply:

- industrial sites in Europe where pipeline supplies are not available;
- filling stations for trucks that use LNG as fuel;
- vessels running on LNG.

From 2018 onwards, the Zeebrugge LNG terminal will offer transshipment services.

The Zeebrugge terminal facilities provide for loading and unloading ships carrying liquefied natural gas (LNG). LNG is stored there temporarily as a buffer in storage tanks and can be regasified and injected into the grid for transmission or loaded back onto LNG ships. More than 1,500 LNG carriers have docked at the terminal since commissioning of the facility in 1987.

LNG ships as small as 2,000 m³ and up to 266,000 m³ can be loaded or unloaded at the Zeebrugge terminal. Up to 380,000 m³ of LNG can be stored into 4 tanks at atmospheric pressure. Over 1,400 LNG ships have been unloaded since 1987, and more than 100 LNG ships have been loaded since 2008. Large ships are loaded every month, for example to supply South America. Since January 2015 also smaller ships are loaded every month to supply remote industrial end consumers and to supply LNG as a fuel for ships and trucks.

LNG trucks and trailers can be loaded with 40 to 50 m³ LNG. Since 2010 over 5,000 loadings have already left Zeebrugge by road and by ferry, in order to supply remote industrial end consumers and to supply LNG as a fuel for ships and trucks in neighboring countries.



Figure 53 - Truck loading in Zeebrugge. Source: Fluxys Belgium company information

3.4.4 Rotterdam²¹

The Rotterdam LNG terminal offers bunkership loading, truck loading and vessel reloading. The facilities are operated by Vopak and Gasunie, the former an independent tank storage company, the latter a European gas infrastructure company which provides the transport of natural gas and green gas in the Netherlands and the Northern part of Germany. The two companies owns 100% of Gate Terminal, where the LNG facilities are located.

Service offered by import terminals in <u>Rotterdam</u>	Status	NAME of installation	Owner/Operator	Min. ship size m ³ LNG	Capacity m ³ /h LNG
Bunkership loading	operational	Gate terminal, Rotterdam	Gasunie, Vopak	5,000	3,000
Bunkership loading	under construction	Gate terminal, Rotterdam	Gasunie, Vopak	500	3,500
Truck loading	operational	Gate terminal, Rotterdam	Gasunie, Vopak		1 x 100
Reloading	operational	Gate terminal, Rotterdam	Gasunie, Vopak	5,000	3,000
Reloading	under construction	Gate terminal, Rotterdam	Gasunie, Vopak	500	3,500
Transshipment	under construction	Gate terminal, Rotterdam	Gasunie, Vopak	5,000	10,000

Table 18 - Services offered by import terminals in Rotterdam. Source: elaboration on GIE

21 Source: Port of Rotterdam, Vopak and Gasunie, Gate Terminal

Gate terminal is the LNG import terminal in Rotterdam, located on the Maasvlakte near the port entrance. Three storage tanks, each with a storage capacity of 180,000 m³, make it possible to unload large amounts of LNG at once. The liquefied natural gas is either regasified at Gate to be transported through an underground pipeline to the European gas distribution network, or it is loaded into vessels or trucks.

Besides the supply to the network of natural gas pipelines, the Gate LNG terminal has facilities to reload LNG into ships, LNG containers or tank trucks. This allows the liquefied natural gas to be distributed by inland tanker, short sea tanker or truck.

Since its start in 2014, truck freight has experienced a strong growth in all market segments: industrial applications, but also as a cleaner fuel for trucks, for inland vessels and for sea-going vessels.

4 LNG market and demand analysis for the target area

From the analysis of the development scenarios of the demand, it has been shown how a large part of the demand will derive from maritime transport in the wake of the increasingly stringent industry regulations on air pollution (e.g: previously discussed global sulphur cap by 2020).

Estimates of the national framework for the maritime sector foresee up to 800,000 tons of LNG in 2025 and 1 million in 2030, with 35 naval units newly-built and fuelled with LNG by 2030. Worldwide currently already 16 large cruise ships powered by LNG are under construction or have been ordered from construction sites; a large part of these will be used in the Mediterranean, to the benefit of the logistics services supporting national ports.

Also on the road sector the potential for development of LNG is considerable, as confirmed by the growing number of registrations of LNG-powered vehicles recorded in recent years, also thanks to the incentives provided by the Ministry of Infrastructure and Transport. According to ANFIA data (National Association of Automotive Industry Chain), only in the first half of 2017, 366 trucks were registered in Italy, weighing more than 3.5 tons, fueled with natural gas, of which 280 were fueled with LNG.

The use of LNG for transport is in fact able to increase the autonomy with respect to compressed natural gas (CNG) while maintaining the advantages in terms of reduced emissions compared to diesel. The liquid state allows, for the same volume, distances approximately 2.5 times those of CNG.

The QSN foresees a demand for LNG for heavy transport equal to 1,250,000 tons at 2025 and 2,500,000 at 2030.

Grounding also on these analyses, a preliminary market study has been assessed within the GAINN4CORE partners and stakeholders and concerns the Tyrrhenian-Ligurian LNG Grid as a whole in the 2025 perspective. The Tyrrhenian-Ligurian LNG network consists of the main port elements of Genova (and Savona), La Spezia and Livorno.

The study of the Tyrrhenian-Ligurian GAINN Grid analyzed in particular the forecasts for use of LNG (in a prudential perspective) of the following elements: ferry industry, cruise sector, smaller ships (eg. High Speed Craft, nautical technical equipment, etc.), land vehicles (trucks and port facilities) and other users (eg. for civil, industrial use).

The study, after assigning the quantities of LNG (m^3) generated per unit/element, assumed an annual LNG demand equal at about $626.088 \text{ m}^3/\text{LNG}$ per year (equals to about 300.000 tons/year) for the Low Scenario

and 1.626.412 m³/LNG per year (equals to about 730.000 tons/year) for the High Scenario. The main outcomes of the analysis per LNG unit/element are below reported.

Element	Low Scenario (n)	High scenario (n)	Low Scenario LNG capacity (m ³)	High Scenario LNG capacity (m ³)	Supply frequency (n/week)	Low Scenario LNG Demand (m ³ /year)	High Scenario LNG Demand (m ³ /year)
HDFs stations	20	50	50	75	1,5	78.000	292.500
Truck Stations for industrial use	30	60	50	75	1,5	117.000	351.000
CNG stations	40	80	50	75	1,5	156.000	468.000
Ferries	2	4	850	850	1	88.400	176.800
Cruises	2	3	2.700	2.700	0,5	140.400	210.600
LNG/NG Bunker ship	3	4	400	400	0,3	18.720	24.960
Minor boats	0	3	50	50	1	0	7.800
Nautical technical services	6	18	35	35	1	10.920	32.760
LNG Shore-side electricity	2	4	50	75	2	10.400	31.200
Other uses (eg. locomotives)	1	4	50	75	1,5	3.900	23.400
Port facilities - Tractors	11	28	0,4	0,4	2,5	572	1.456
Port facilities – Reach stacker	11	36	0,4	0,4	3,5	801	2.621
Port facilities – RMG-RTG	5	17	1,5	1,5	2,5	975	3.315
TOTAL						626.088	1.626.412

Table 19 – GAINN_IT overall Tyrrhenian-Ligurian Grid LNG demand - 2025 scenario (m³ LNG/year)

Element	Low Scenario (n)	High scenario (n)	Low Scenario LNG capacity (m ³)	High Scenario LNG capacity (m ³)	Supply frequency (n/week)	Low Scenario LNG Demand (ton/year)	High Scenario LNG Demand (ton/year)
HDVs stations	1	1	50	75	1,5	1.755	2.633
Cruises	1	2	2.700	2.700	0,5	31.590	63.180
Minor boats	0	2	50	50	1	0	2.340
Nautical technical services	2	6	35	35	1	1.638	4.914
LNG Shore-side electricity	1	2	50	75	2	2.340	7.020
Other uses (eg.industrial/loco motives)	1	3	50	75	1,5	1.755	7.898
Port facilities - Tractors	4	12	0,4	0,4	2,5	94	281
Port facilities –	4	12	0,4	0,4	3,5	131	393
Reach stacker	2	6	1,5	1,5	2,5	176	527
TOTAL						39.478	89.184

Table 20 Port of La Spezia LNG demand - 2025 scenario (ton LNG/year). Source: elaboration of the author from GAINN_IT.

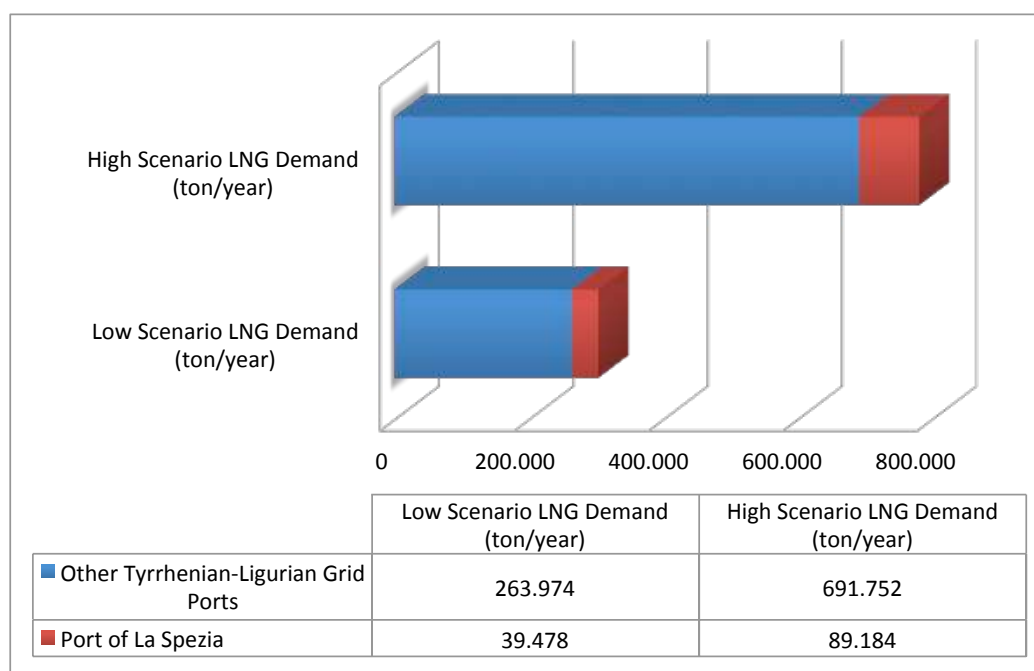


Figure 54 – Comparison between Port of La Spezia and Other Tyrrhenian-Ligurian Grid Ports LNG demands - 2025 scenario (ton LNG/year). Elaboration on GAINN_IT

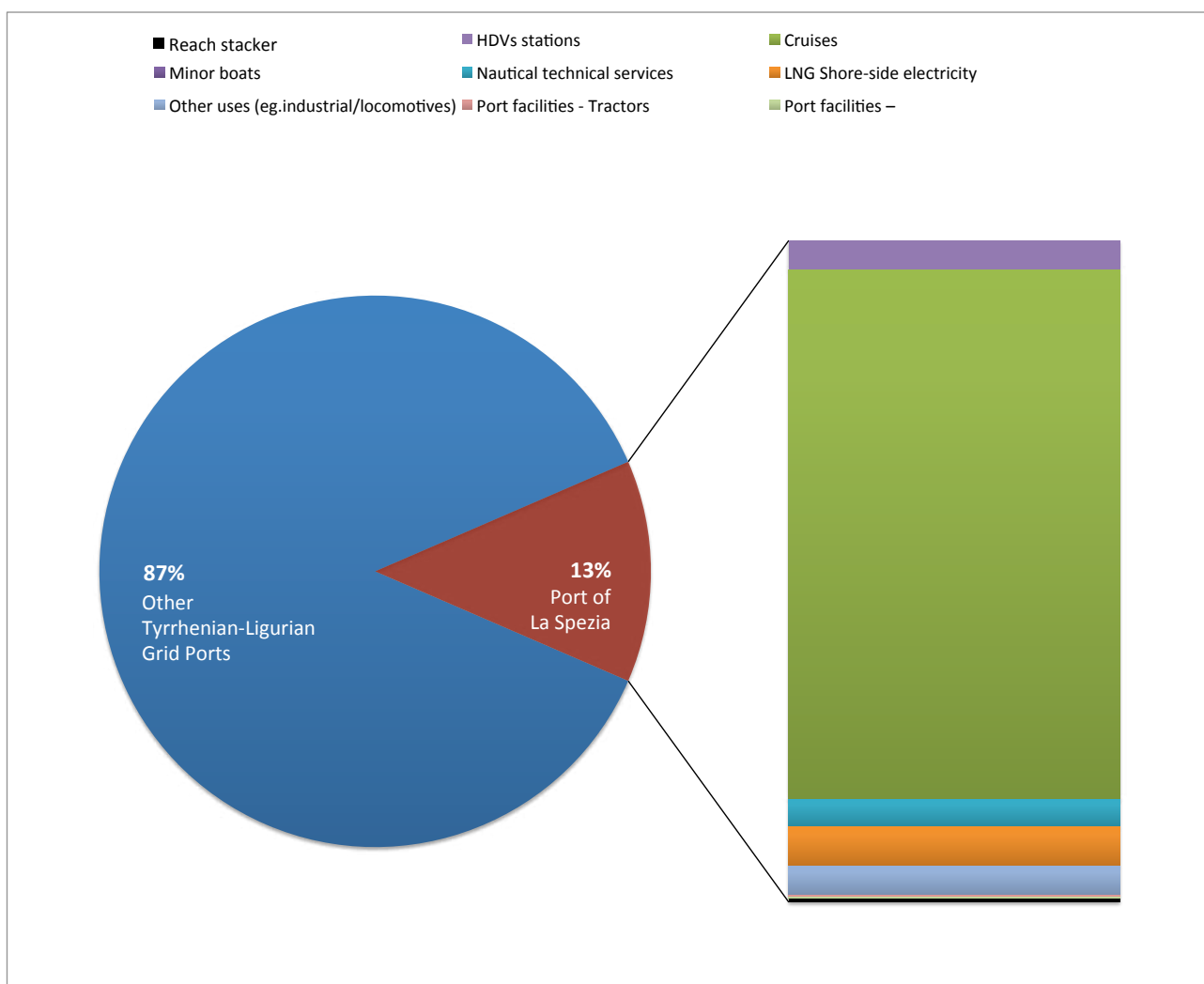


Figure 55 – Port of La Spezia LNG demand distribution - 2025 scenario (ton LNG/year). Elaboration on GAINN_IT

5 Study's assumptions, location and sizing hypothesis of satellite storage in the Port of La Spezia

The studies and analysis related LNG supply system for La Spezia Port have been carried out taking into consideration 2 possible solutions:

- Receive and feed LNG from the Panigaglia regasification Terminal through Small Scale LNG services by small bunkering ships/barges (with technical structural modifications) or by truck; and
- Receive and feed LNG from other sources, including LNG bunkering ships by sea and/or LNG truck/ISO-containers by land.

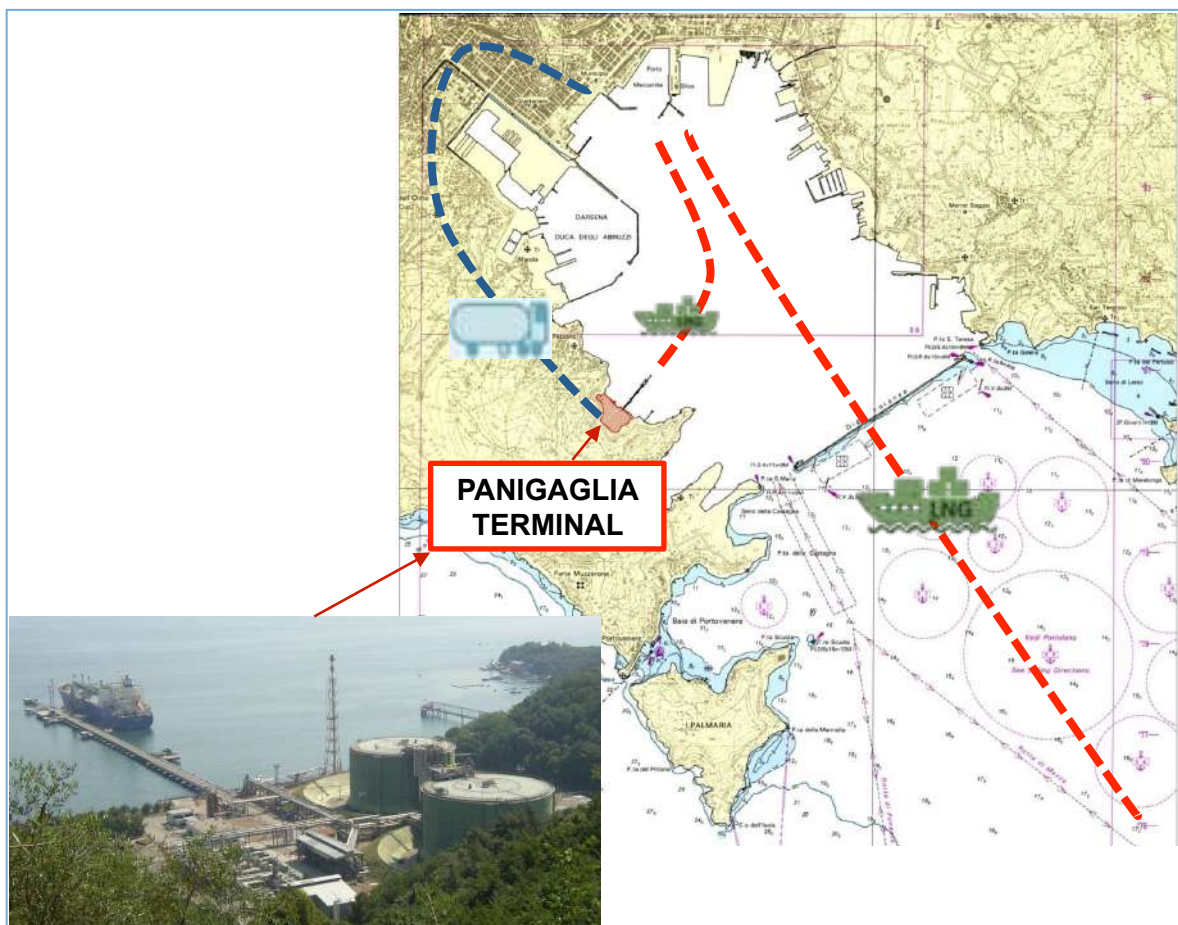


Figure 56 – LNG supply options for the Port of La Spezia

To this end, the identification, within the port, of a suitable area for the installation of an intermediate storage that could be fed by a larger import regasification plant and used to directly load LNG trucks and/or bunkering vessels is a crucial step that must take into account the overall Port system, the existing facilities, local provisions, space availability and access by road, rail and sea.

The storage should be supplied by trucks or by barges and feeder vessels and is expected to be used for different kind of operations:

- Supply trucks which transport LNG all around Italy;
- Supply trucks which transport LNG to the inland terminal;
- Supply the port vehicles, if their retrofit to LNG has been done;
- Supply ships through the use of bunker vessels;
- Receive LNG from carrier vessels;

The area assumed for the location of the intermediate storage is Terminal Ravano, owned by Conship Italia with an overall extension of more than 90.000 m², now occupied mainly with trucks and containers.

The following image shows the area assumed for the location of the intermediate storage.



Figure 57 - Terminal Ravano's map for LNG temporary storage's location

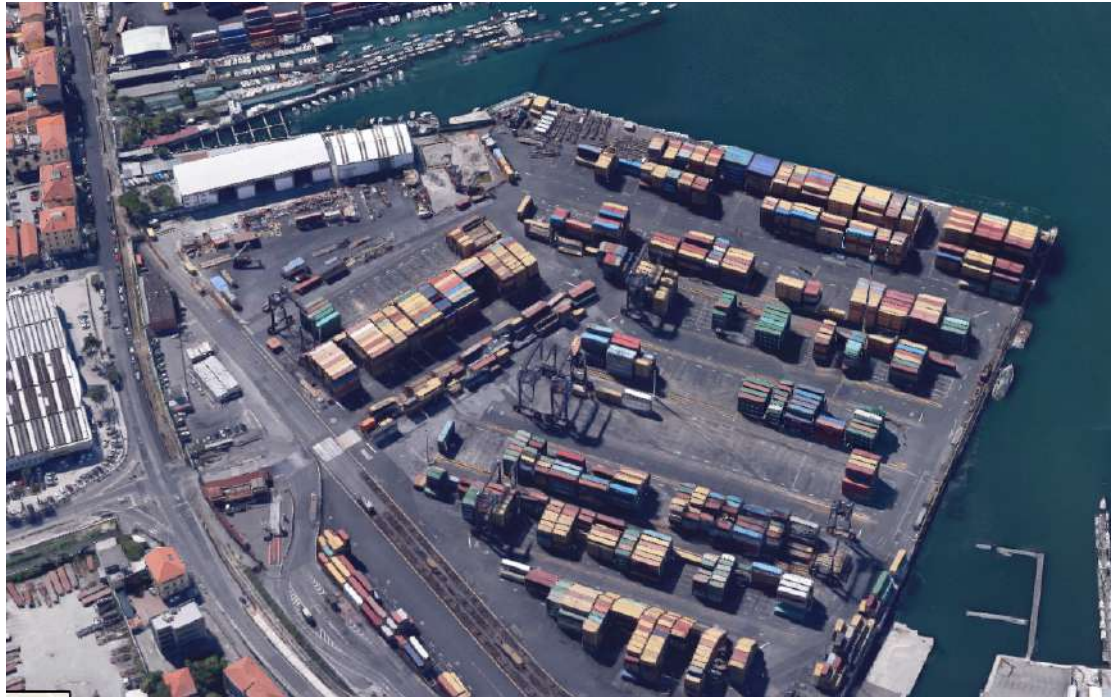


Figure 58 - Terminal Ravano "as is situation".

The indicated location has been chosen considering the poor free zones near the Port and the need to locate the two sites in a strategic position for trucks and vessels movements, connected to LNG market.

The layout below shows the area considered, so that main communication ways have been crossed and serviced: by road, sea and rail.

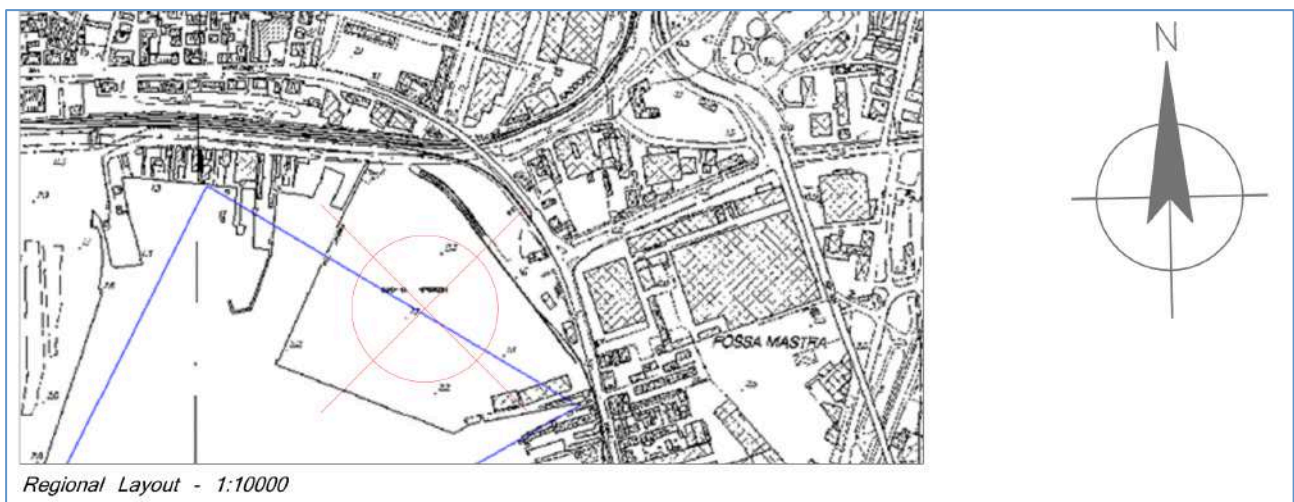




Figure 59 – Layout of the main access ways to the identified site for LNG storage location.

The new LNG storage systems should be conceived with the aim of receiving and unloading small tankers, storing LNG in cryogenic tanks capable of supporting temperatures below -160°C and of loading tankers/ bunker ships for distribution to end users.

The LNG port storage hypothesis is to be modular and expandable in the following phases:

- Phase 0: storage capacity of 500 m^3 ;
- Phase 1: storage capacity of 3.000 m^3 ;
- Phase 2: storage capacity of 6.000 m^3 .

The supposed capacity is in line with the ratio between the storage capacity of similar projects and their estimated total LNG turnaround on a yearly basis. Suitable conversion factors have been used for the purpose.

Phase 0 will ensure a turnaround sufficient to meet the demand of the lower-case scenario depicted in chapter 4, without considering cruise ships' related needs, thus accounting for a total of around 7.800 tonnes of LNG/year. The 3.000 m^3 LNG capacity of Phase 1 will guarantee a total turnaround of 40.000 tonnes LNG/year, covering the demand of the overall lower-case scenario. Finally, Phase 2 will ensure a turnaround of 90.000 tonnes LNG/year consistent with the estimated overall demand of the higher-case scenario for the Port of La Spezia.

	← multiply by →					
	Tonnes LNG	m ³ LNG	Nm ³ gas	ft ³ gas	mmBtu	boe
Tonnes LNG		2.222	1,300	45,909	53.38	9.203
m ³ LNG	0.450		585	20,659	24.02	4.141
m ³ gas	7.692 x 10 ⁻⁴	0.0017		35.31	0.0411	0.0071
ft ³ gas	2.178 x 10 ⁻⁵	4.8 x 10 ⁻⁵	0.0283		0.0012	2.005 x 10 ⁻⁴
mmBtu	0.0187	0.0416	24.36	860.1		0.1724
boe	0.1087	0.2415	141.3	4,989	5.8	

Table 21 – LNG conversion table. IGU pocketbook.

The modular approach uses multiple, smaller and standard LNG tanks to achieve total plant's capacity, as opposed to a custom engineered stick-built facility, and would allow the Port of La Spezia to scale its project and costs with the following main advantages:

- a) Serve immediate off-takers and expand plant capacity as demand grows;
- b) Reduce the plant's planning, engineering, permitting and construction schedule;
- c) Reduce CAPEX while allowing for a quicker ROI starting generating revenues faster;
- d) Reduce operational risk.

To be noted that the "Phase 0" includes the whole predisposition of the infrastructure and the plant, with a small LNG storage system of about 500 m³ (falling below the threshold established by the Seveso Directive), acting as a buffer and first case study for port refuelling operations and local distribution (e.g. feeding with LNG port vehicles, road tankers and/or ISO containers).

The modular tanks, conceived to be economically viable until Phase 2, could be of two main types:

- at atmospheric pressure (which would ask for great cautions in the control of the increase of inside pressure and which would mostly seem anti-economic in the case of small storage systems)
- pressurized (which would also allow the storage of LNG for different days without issues related to the increase of the inside pressure).

The main widespread option for cases similar to that in subject seems to be the one of pressurized tanks, foreseeing a series of horizontal cryogenic bullet tanks whose number will be defined according to the evolution of LNG demand in and outside the port area.

Several products are already on the market allowing this configuration, one of the leading manufacturers and suppliers being Chart Ferox, whose ET Series storage tanks can be considered as a reference.

Approximate Volume	[m ³]	89	98	108	123	140	154
Outer Diameter	[mm]	3000			3200	3500	
Approximate Height	[m]	19.68	21.54	23.34	23.70	22.10	24.00
Approximate Weight MAWP 11 (9) bar	[kg]	32060	34820	37570	45800	53500	57100
Approximate Weight MAWP 17 bar	[kg]	38700	42100	45400	49200	57000	61100
Approximate Volume	[m ³]	169	186	202	235	257	279
Outer Diameter	[mm]	3900			4300		
Approximate Height	[m]	22.10	24.10	26.10	24.20	26.20	28.20
Approximate Weight MAWP 8 (6) bar	[kg]	60500	64700	69700	80500	86400	92500
Approximate Weight MAWP 13 bar	[kg]	66300	71300	76800	86300	92800	98900
Approximate Volume	[m ³]	301	335	363	392	420	450
Outer Diameter	[mm]	4300	4800				
Approximate Height	[m]	30.20	26.50	28.50	30.50	32.50	34.50
Approximate Weight MAWP 6 bar	[kg]	98500	108800	115800	122300	128500	128500
Approximate Weight MAWP 13 bar	[kg]	105600	112700	120100	128100	135500	142800
Approximate Volume	[m ³]	500	683	1000	1225		
Outer Diameter	[mm]	5000	5600	5800	6000		
Approximate Length	[m]	34.6	36.60	50.00	55.00		
Approximate Weight MAWP 8 bar	[kg]	136100	163500	220000	255000		

Table 22 – Specifications of the Chart's ET series storage tanks for modular LNG plants. Chart Industries company information

Such products have been recently adopted by other best-practice cases such as those depicted below, showing the capability of expansion and allowing for contained overall dimensions.



Figure 60 – Modular and expandable LNG storage at the port of Hamburg. Chart Industries company information.

With a configuration similar to that proposed for the Port of La Spezia, the Klaipeda multi-purpose LNG plant comprises five identical horizontal vacuum insulated storage tanks, each with a capacity of 1.000 m³, ten ambient air vaporizers for gas delivery, twin trailer loading bays, which can simultaneously fill two trailers, four cryogenic submerged pumps for truck filling and bunkering, interconnecting pipework, emergency flare and all associated control and safety systems.

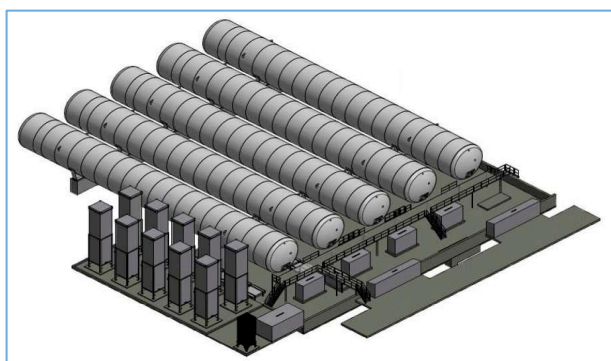


Figure 61 – Klaipeda - multipurpose LNG plant. Chart Industries company information

Given the proven reliability of the concept and of the technology and products used, a layout scheme for the case study port inside the boundaries of the envisaged site of Terminal Ravano has been elaborated, in order to come up with an overview of the overall sizing of the possible plant in full configuration.

Plant's modules have been envisaged to be those of a typical configuration for this kind of plants as per manufacturer's solutions' catalogue.

Possible location has been envisaged taking into account the existing access ways inside the terminal, in particular to allow the loading and unloading of tanker trucks.

Regarding the distance between the storage and the quay, the configuration hereinafter proposed takes into serious account that one of the biggest issue is cost-related, since cryogenic pipes could be very expensive: if the plant is closer to the quay, the cost of the piping is lower and the risk factor too.

Figure below shows the scalability of the plant according to the evolution of the market as follows: configuration for phase 0 with one bullet tank of 500 m³ (left), phase 1 with 2 bullets of 500m³ each and 2 tanks of 1000m³ (middle) and phase 2 with 6 identical horizontal vacuum insulated storage tanks of 1000m³ each (right).



Figure 62 – Sizing hypothesis for modular LNG storage layout in Terminal Ravano.

As can be seen from figure below, showing (left) the overall Terminal Ravano with the plant in full configuration (phase 2), the sizing of the installation could be rather limited. The area needed for the construction of the LNG plant as outlined above (therefore up to Phase 2 corresponding to a capacity of 6.000 m³) would be in fact around 5000m², without considering the safety zone perimeter. The plant will be also simple in terms of elements, for which a layout scheme has been elaborated below (right).

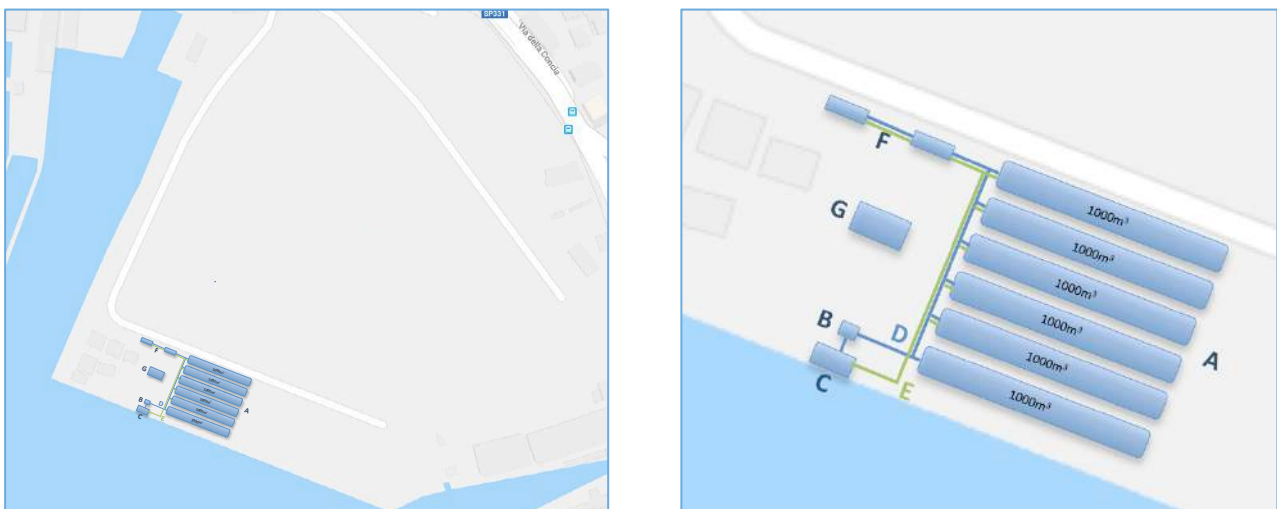


Figure 63 – Overall view of the Terminal Ravano with the plant in phase 2 configuration and detail of the plant's main components.

The elements of the plant highlighted in the layout scheme above are the following:

- A. **Vacuum insulated tank(s)**: Pressurized insulated LNG storage tanks with volume up to 1225m³ each (in this case 6 tanks of 1000m³ LNG capacity each);
- B. **LNG transfer pump**: Cryogenic transfer pump with ability to adjust flow rates to the requirements/capabilities of the receiving vessel;
- C. **Jetty filling module**: LNG supply and gas return connection with hoses and dry quick couplings. Also break away couplings and flow meters are part of this module. Hoses may be supported by crane for easy handling and height adjustment (height differences of ship's bunker stations and/or tidal height differences). For larger installations a loading arm can be applied;
- D. **LNG piping**: Vacuum insulated or foam insulated LNG transfer lines;
- E. **Gas return piping**²²: Stainless steel gas return piping;
- F. **Truck loading/offloading module(s)**: Hose connection for LNG delivery to (or withdrawal from) the storage tanks by truck or ISO container. This module is typically equipped with a pump and flow metering equipment;
- G. **Control station & safety system**: consisting of a main switchboard, PLC touch panel and all safety instrumentation like gas detectors, flame detectors, LNG leak detectors and ESD pushbutton(s). Uninterrupted power supply is ensured by batteries. Remote data transmission is optionally available.

With such a configuration, the facility would be capable to demonstrate the economic and technological viability of small-scale LNG storage and distribution.

Although unable to provide the same economies of scale as the largest LNG terminals, the plant in the Port of La Spezia could be built in a significantly shorter time frame and would provide operational flexibility. This creates an attractive business model for terminal operators and owners to quickly address the growing demand for LNG as a fuel for transportation and energy and take advantage of new supply.

²² LNG vaporizers may be also foreseen with the idea of refuelling CNG units or connecting to the gas grid. However, giving the proximity of the Panigaglia regasification terminal and keeping the focus on LNG, these may be avoided and are thus not considered in the sizing hypothesis.

A further and additional deepened hypothesis, particularly for the transitory phase of start-up, is that of the installing a floating storage that could better answer to the transition phase to the new fuel, while waiting for a consolidation both on the demand side and on the location of the plant in the port of La Spezia, in order to then achieve a definitive solution in terms of capacity, better location and layout.

Moreover, it is to be noted that the floating storage solution could reduce the uncertainty and burdens associated with the planning, authorization and construction phase. Another advantage would be the reduction of land use, as well as the opportunity of limiting possible oppositions of citizens, being it a removable system. Nevertheless, further analysis should be carried out for the floating storages hypothesis.

6 Cost and transit time simulations for LNG supply from alternative sources

6.1 *Cost and transit time simulations methodology*

The simulations are consistent with the services offered (or soon to be offered) both by LNG terminals and by transport operators, but still include some theoretical elements.

The simulations regarded both international sources and the possibility of supplying at Panigaglia, in anticipation of the potential realization of a Small Scale LNG facility by GNL Italia.

Two different kind of simulations were carried out. The first one regarded supplying of LNG from international terminals – Marseille, Barcelona, Zeebrugge and Rotterdam.

Marseille and Barcelona were selected for being the nearest ports both by sea and by road. Other Spanish ports were not included because, given the methodology used, cost estimates would have been analogous and transit times superior. Other ports in Mediterranean were not included because distances were almost the triple than from Barcelona to La Spezia.

Zeebrugge and Rotterdam were chosen for being the nearest by road soon after Marseille and Barcelona. The inclusion of Zeebrugge and Rotterdam also results useful allowing to test cost and transit time for a railway option (transport of an ISO Container by train) via Melzo.

For these potential points of supply, different transport option were tested: by sea (both containership and tanker) and by road for Marseille and Barcelona; by road and railway for Zeebrugge and Rotterdam. The main simulation results are expressed in euro per ton, thus allowing to compare different mode of transport and handling of the freight. For ship transport both containership transport and tanker ship transport have been considered. For road and railway transport, available data don't allow to distinguish costs between container and tanker transport, so the results can be considered as an average for both options (however keeping in mind that train tanker is not a diffused mode of transport up to now).

The respective cost and transit time have therefore been applied, as illustrated in next paragraphs for every simulation.

For every simulation must be kept in mind that LNG ISO Containers and tanker ships represent peculiar typologies, respectively, of container and bulk ships (given the specific characteristics of the freight) and therefore the estimated costs can only be considered approximate for that specific mode of transport.

The 2016 study reports, separately for import and export flows and for each mode of transport, average freight rates (ancillary services included²³), for different geographic areas in 2015. It is the main source the study relied on, being the most updated and capable of approximating concrete cases.

The 2014 study reports, separately for imports and exports and for the different modes of transport, international transport costs in euro cents per ton-kilometre for 2012. Starting from the measured distances in kilometres, a simulation was carried out also using these data. Results of this second elaboration confirmed the choice to use the data of the 2016 study. Data contained in the 2016 study, in fact, although not expressible in terms of cost per kilometre, is preferable, as well as more updated, also because it allows to keep under control economies of scale (decreasing average costs with increasing distances) and local circumstances in the determination of transport rate. With respect to this second point, for example, a recent study reports that the annual gross salary of an international driver is about 20,000 euro in Spain and 30,000 in France (CNR, 2015).

In order to estimate transit time, kilometric distances were calculated in the first place using the calculation engine provided by EcoTransIT.²⁴ After that, applying to kilometric distances some speed parameter differentiated by mode of transport, transit time were estimated. For road transport mandatory rest time for drivers was considered as well.²⁵ For the transit time estimation, standby, loading and unloading times were not considered. Transit time must then be considered as “pure transit time”. However some consideration about standby time and handling time for container transport by rail are reported in dedicated paragraph.

As for supplying from Panigaglia, a different kind of estimation was realized, with the purpose of estimating time and cost of transport for a single barge/truck load. In the case of road transport, transport with an ADR tanker truck with a total laden weight exceeding 26 tons was considered, for transport by sea the use of a self-propelled barge.

23 For example commissions paid to shippers and agents, tolls and handling services.

24 The methodology behind EcoTransIT was developed by the German Institute for Energy and Environmental Research (IFEU - Institut für Energie und Umweltforschung) in Heidelberg, and by Rail Management Consultants GmbH (RMCon), and IVE mbH, within a research project founded on the initiative of European railway companies including Trenitalia, SNCF, DB Schenker, OBB.

25 A stop of at least 45 minutes is required after a drive period of 4.5 hours and in the arc of 24 hours the driver is requested to have a minimum rest period of 11 consecutive hours.

The road transport cost per unit was derived from the trucking operating costs published in detail per type of vehicle by the Ministry of Infrastructure and Transport²⁶. The used cost includes depreciation, maintenance, tires, cost of labor, fuel, and other factors.

Road distance was calculated both via Google Maps and Tom Tom. This second platform, in particular, allows to set parameters for a heavy truck, its laden weight and hazardous goods transportation.

The barge cost was derived by hourly cost included in price lists for public works published by local public administration bodies. Distance between Panigaglia and the port of La Spezia (3.5 km) was measured on Google Maps.

Road transit time was calculated on Tom Tom website. Ship transit time was calculated assuming an average speed of 3 knots (5.6 km/h).

6.2 Main results of the simulations

The results of the simulations on cost and transit time are hereinafter presented and discussed in paragraph 6.3.

As far as the unitary costs associated to each supply route, table below recaps the voices in terms of euro/tonne to transport LNG from selected international points of supply, for each applicable transport mode.

Mode of transport	Euro per tonne			
	Marseille	Barcelona	Zeebrugge	Rotterdam
Container ship	96	96	-	-
Tanker ship	80	69	-	-
Road	116	100	116	116
Rail	-	-	51	51

Table 23 - Simulated transport costs for selected international points of supply

²⁶ Last update on July 2014.

Similarly, transit time for each route is hereby provided.

Mode of transport	Transit time (hours)			
	Marseille	Barcelona	Zeebrugge	Rotterdam
Container ship	14	19	-	-
Tanker ship	14	19	-	-
Road	9	19	25	25
Rail	-	-	33	37

Table 24 - Simulated transit time for selected international points of supply

Considering the typical payload of an ISO Container, cost of transport for a single container were also calculated and reported in the table below.

Mode of transport	Euro per ISO Container (40 foot)			
	Marseille	Barcelona	Zeebrugge	Rotterdam
Container ship	1.723	1.723	-	-
Road	2.092	1.804	2.093	2.093
Rail	-	-	909	909

Table 25 - Simulated transport costs for one ISO Container (40 foot)

Marseille – La Spezia

A cost of 96 euros per ton is estimated for container ship transport from Marseille, 80 euro-ton by tanker ship and 116 by road. Transit time (standby, load and unload excluded) is 14 hours by sea and 9 by road. The sea option results more convenient in relation to costs while road option results faster.

Mode of transport	Simulation results	
	Cost (euro-ton)	Transit time (hours)
Container ship	96	14
Tanker ship	80	14
Truck	116	9

Table 26 - Simulation results (transport costs and transit time) of LNG supplying from Marseille

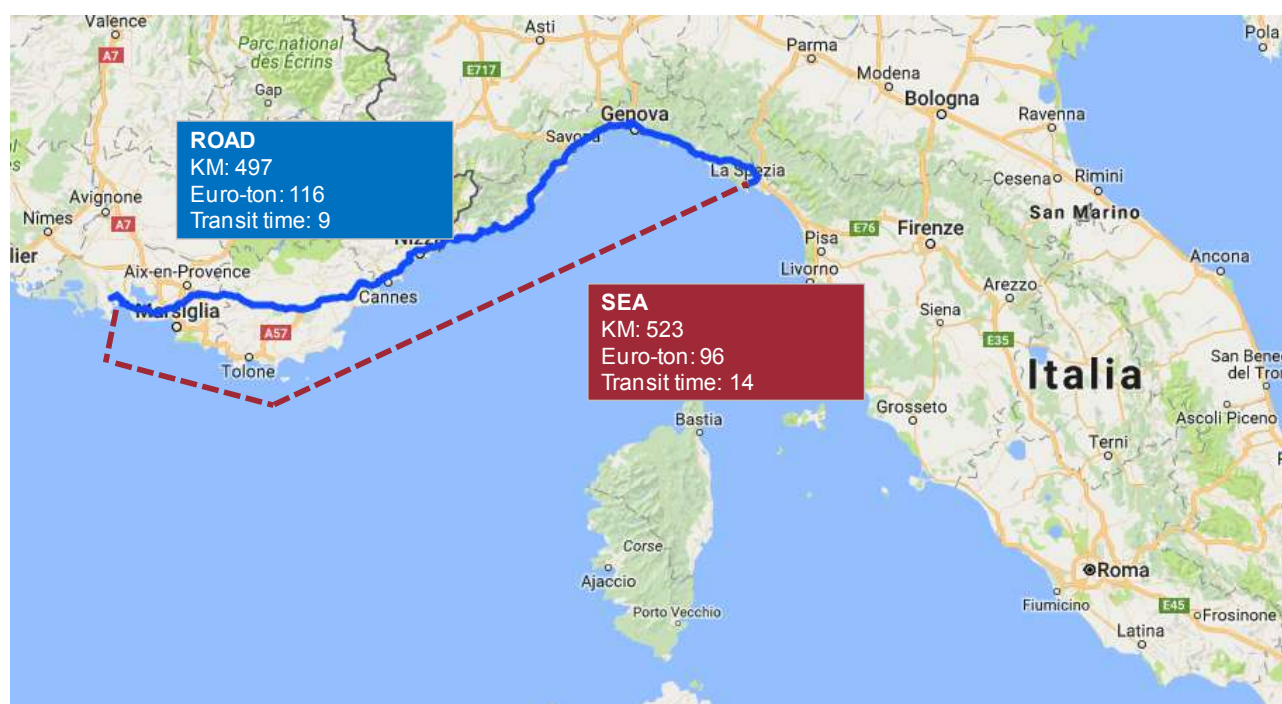


Figure 64 - Road and sea (containership) simulation for Marseille – La Spezia

Barcelona – La Spezia

The simulation for supplying from Barcelona returns a cost of 100 euro-ton by truck, 96 by container ship and 69 by tanker ship. Transit time is 19 hours both by road and sea.²⁷

Mode of transport	Simulation results	
	Cost (euro-ton)	Transit time (hours)
Container ship	96	19
Bulk ship	69	19
Road	100	19

Table 27 - Simulation results (transport costs and transit time) of LNG supplying from Barcelona

²⁷ The road transport costs result lower for imports from Spain than from France. Although not possible to estimate retrospectively the input values that determine this result, it's possible to suppose that it derives from different levels of the cost components in the two nations, such as fuel prices and drivers' wages.



Figure 65 - Road and sea (containership) simulation for Barcelona – La Spezia

Zeebrugge – La Spezia

The simulation compares a road option with a rail itinerary with interchange at Melzo intermodal center.

According to the estimates, road transport is 116 euro per ton and rail transport 51 euro-ton. Transit time is 25 hours by road and 33 by rail.

Mode of transport	Simulation results	
	Cost (euro-ton)	Transit time (hours)
Road	116	25
Rail	51	33

Table 28 - Simulation results (transport costs and transit time) of LNG supplying from Zeebrugge

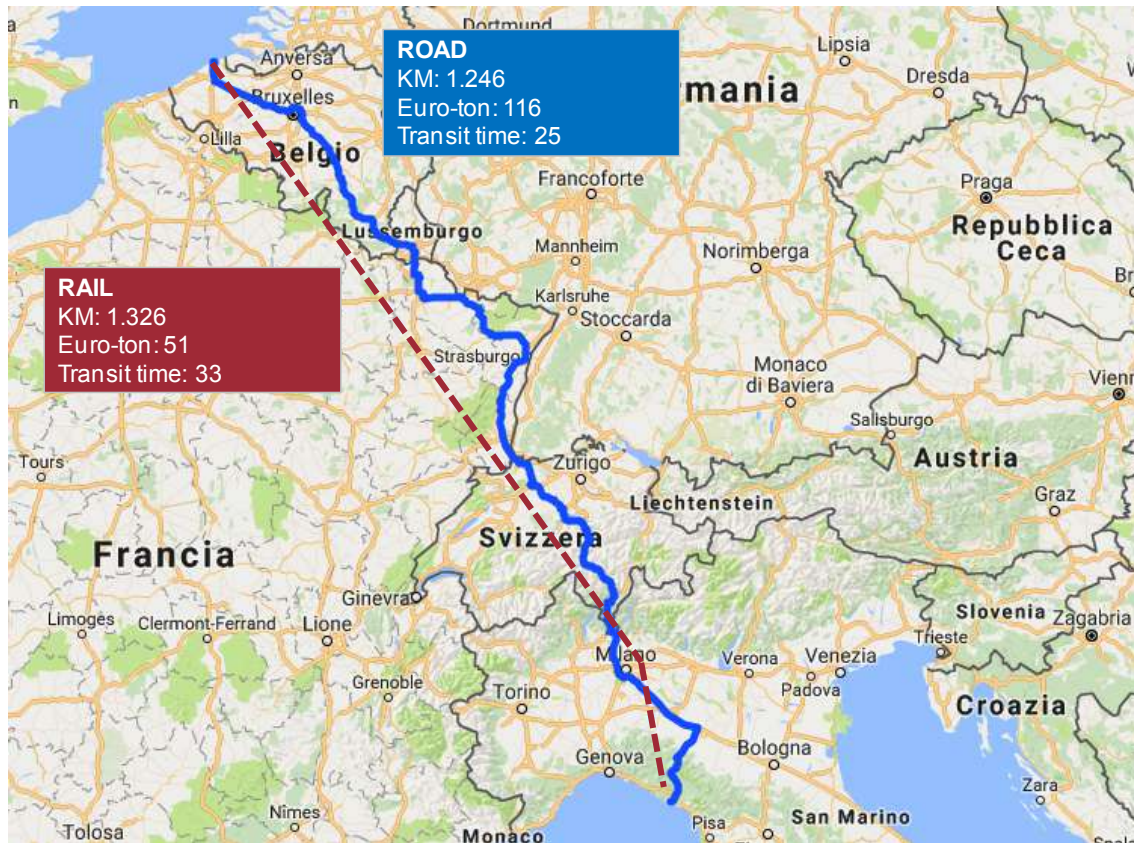


Figure 66 - Road and sea (containership) simulation for Zeebrugge – La Spezia

Rotterdam – La Spezia

The simulation compares a road option with a rail itinerary with interchange at Melzo intermodal center.

According to the estimates, road transport is 116 euro per ton and rail transport 51 euro-ton. Transit time is 25 hours by road and 37 by rail.

For this simulation transit time has been derived from data sheets published by operators which offer freight transport services on the Rotterdam – Melzo – La Spezia route.

Mode of transport	Simulation results	
	Cost (euro-ton)	Transit time (hours)
Road	116	25
Rail	51	37

Table 29 - Simulation results (transport costs and transit time) of LNG supplying from Rotterdam

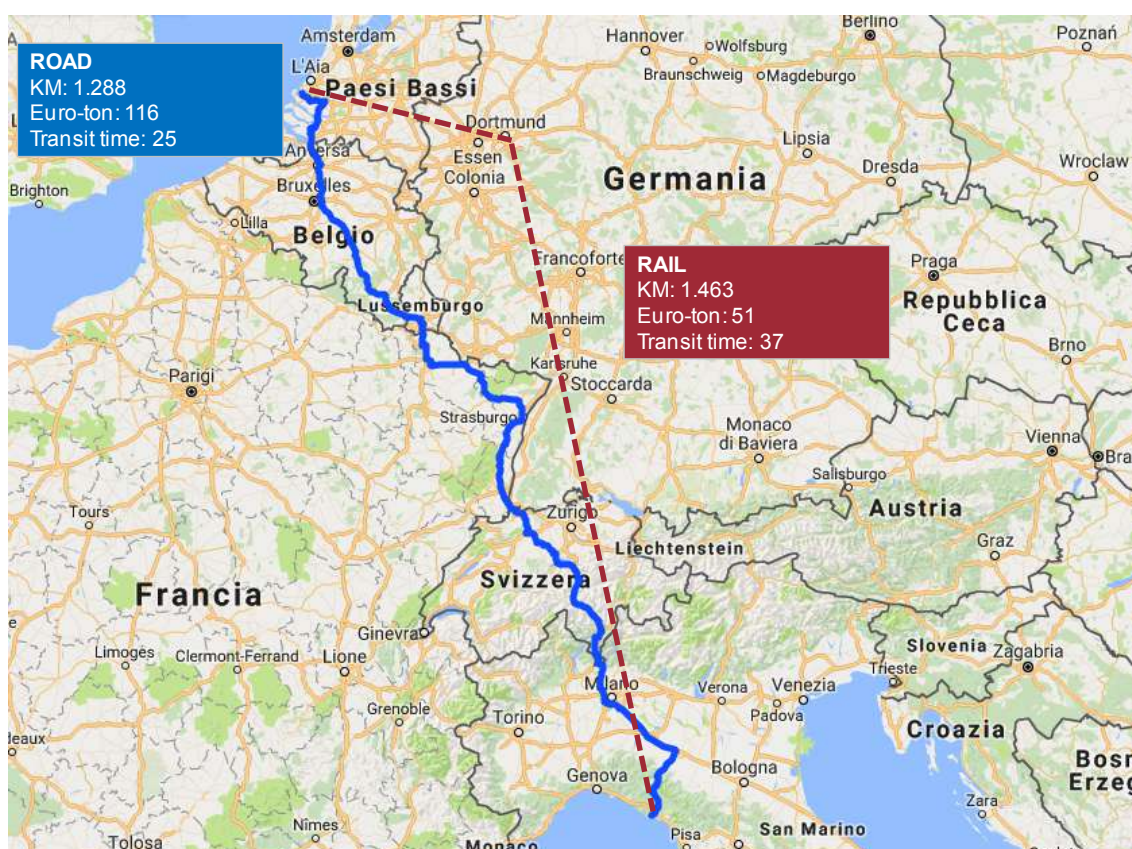


Figure 67 - Road and sea (containership) simulation for Rotterdam – La Spezia

Panigaglia – La Spezia

Estimation of “pure” (standby and handling excluded) transit costs and time of LNG supplying from Panigaglia returns 30 euros per load by barge and 20-25 euros by truck. Transit time is 40 minutes for both options.

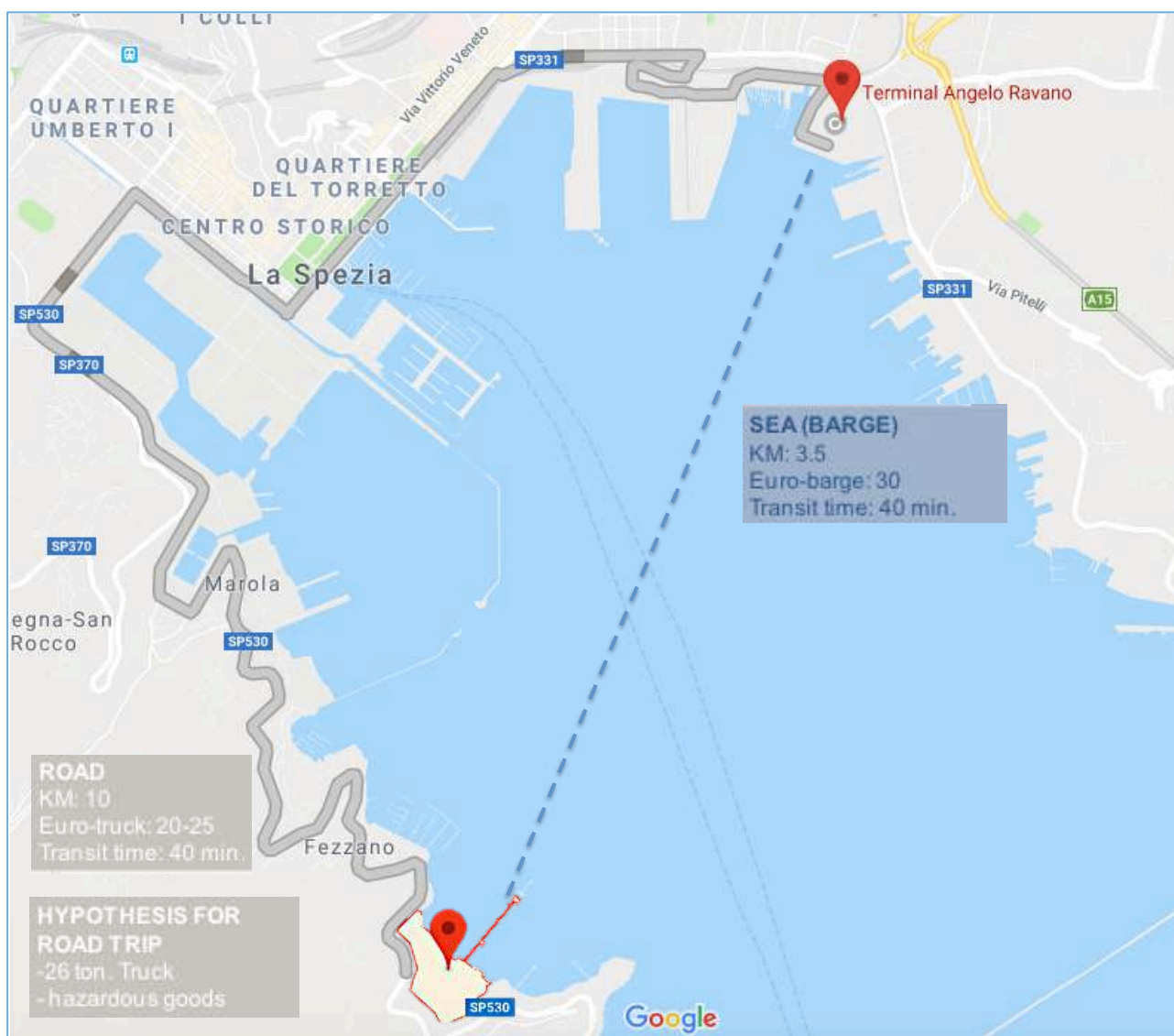


Figure 68 - Road and sea (barge) simulation for Panigaglia – La Spezia

Standby and handling time for container transport by rail

In addition to transit time determined by the coverage of the distance to be travelled, the time needed to take a container from the rail yard of origin to the rail yard of destination includes other voices such as standby in terminals and handling of the container.

Taking as reference operational time for an actual existing service, it's possible to estimate standby and handling time in the order of 20-32 hours. Once available for departure from the rail terminal, the container will actually be on the move after 12-24 hours needed for rail loading and wagon load completion and 3 for shunting (sorting and moving items of rolling stock into the complete train set). After arrival at the terminal destination, 5 hours are needed to discharge the train.

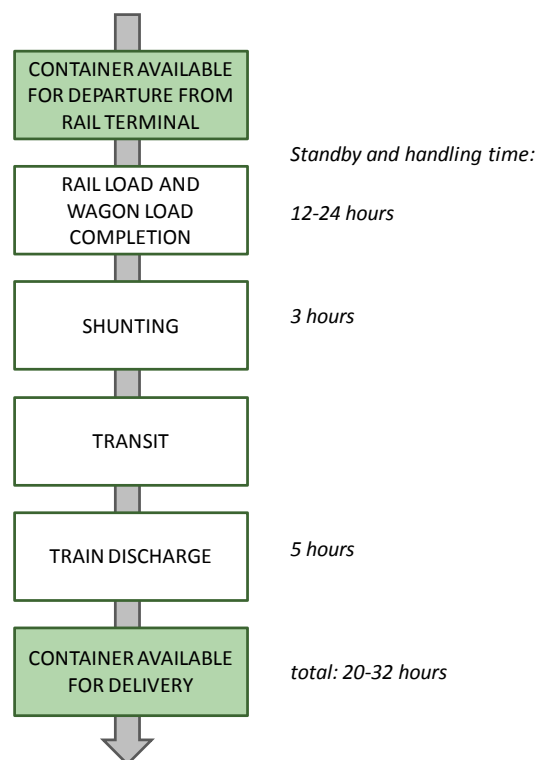


Figure 69 - Standby and handling time for a container transported by train

Theoretical cost to be sustained for the entire demand of LNG at La Spezia

Considering the demand of LNG estimated for La Spezia in two different scenarios, transport costs to be sustained for supplying the necessary amount of LNG have been estimated. Estimation consisted exclusively of a reparametrization based on average costs and must therefore be considered carefully.

Mode of transport	Cost of transport for annual demand (mio euro)			
	Lower-case scenario			
	Marseille	Barcelona	Zeebrugge	Rotterdam
Container ship	3,8	3,8	-	-
Bulk ship	3,2	2,7	-	-
Road	4,6	4,0	4,6	4,6
Rail	-	-	2,0	2,0

Table 30 - Cost of transport for annual demand (Mio euro). Lower-case scenario

Mode of transport	Cost of transport for annual demand (mio euro)			
	Higher-case scenario			
	Marseille	Barcelona	Zeebrugge	Rotterdam
Container ship	8,5	8,5	-	-
Bulk ship	7,1	6,1	-	-
Road	10,4	8,9	10,4	10,4
Rail	-	-	4,5	4,5

Table 31 - Cost of transport for annual demand (Mio euro). Higher-case scenario

6.3 Discussion on cost and transit time simulations for LNG supply from International Terminals

Ship transport results to be more convenient, from an economic point of view, for supplying from Marseille and Barcelona. For supplying from Zeebrugge and Rotterdam, costs by rail result to be lower for the road option than for the railway one. Considering road transport, potentially available for all origins, Barcelona results the most convenient while the others are on the same level. According to the simulation, rail supplying from Zeebrugge or Rotterdam should be more expensive than maritime supplying from Marseille or Barcelona.

As for “pure” transit time, road supplying from Barcelona results the fastest among all options while rail from Zeebrugge or Rotterdam the slowest (and considering that standby and handling times are not considered, total transit time by rail is even higher).

In this regard, it is noticeable that rail transport of LNG is not widespread at present. The main case of diversification in terms of logistic solution is represented by the experience of Liquimet S.p.A. that supplies its C-LNG truck refueling station located at Interporto Padova (one of the most important rail-road terminals in the Veneto Region) through ISO-containers loaded with LNG at the Belgian terminal of Zeebrugge, then transported by rail to Italy via the carrier Contship (that in turns manages the rail-road terminal of Melzo (near Milan)).

As far as the currently available International LNG terminals offering LNG SS services are concerned, supplying the Port of La Spezia from Barcelona results to be the most feasible option from an economic point of view, despite the distance is shorter than for Marseille.

In particular, road transport costs result lower for imports from Spain than from France.

Although it is not possible to retrospectively estimate the input values that determine this result, it's possible to suppose that it derives from different levels of the cost components in the two nations, such as fuel prices and drivers' wages.

However, it seems that the real world differs from the simulated reality. This consideration can find a kind of confirmation in the analysis of the present situation regarding LNG supply in Italy. It is in fact to be noted that Marseille-Fos is at present the main supply source of LNG for Italy via tanker trucks, being understood that the LNG does not serve for the time being the maritime domain.

LNG is in fact delivered mainly to industry plants such as those enlisted in table below (via satellite storages) and to a certain extent used to supply the C-LNG refuelling stations for road transport (both via satellite storages and by delivering LNG directly to the stations).

Company	Region	Province	City	Year of operation
Ferrero Mangimi S.p.A.	Piemonte	Cuneo	Farigliano	2015
Norda S.p.A.	Emilia Romagna	Parma	Bedonia	2014
Speziali s.r.l	Emilia Romagna	Mantova	Roncoferraro	2015
Forno Bonomi S.p.A.	Veneto	Verona	Roverè Veronese	2015
Craver s.r.l.	Veneto	Verona	S. Martino di Buonalbergo	2014
Levissima	Lombardia	Sondrio	Cepina Valdisotto	2015
VIS s.r.l.	Lombardia	Sondrio	Lovero	2016
Mario Costa S.p.A.	Piemonte	Novara	Casalino	2014
Fiat Chrysler Auto - FCA	Piemonte	Vercelli	Balocco	2015
Acqua Panna	Toscana	Firenze	Scarperia	2016
Rivoira	Piemonte	Cuneo	Verzuolo	2016
Acqua Minerale di Calizzano S.p.A	Liguria	Savona	Calizzano	2017
Lederplast	Piemonte	Torino	Pessinetto	2017
Latteria Sociale Mantova Soc. Agr. Coop.	Lombardia	Mantova	Porto Mantovano	2018
Coop. ARBOREA	Sardegna	Oristano	Arborea	2015
Trade Broker	Lombardia	Cremona	Casalbuttano	2014
Lavarent S.r.l.	Trentino Alto Adige	Bolzano	Sarentino	2014
FFS	Trentino Alto Adige	Trento	Ossana	2013
Olimpia Due	Emilia Romagna	Rimini	Verucchio	2015

Table 32 - Off-grid users supplied by LNG satellite storages in Italy. Elaboration on REF-E data (2018)

Plant owner/manager	Region	Province	City	Year of operation
Concessionaria TotalErg	Piemonte	Torino	Poirino	2011
Rudy Baraldi	Emilia Romagna	Bologna	Calderara Di Reno	2012
Concessionaria ENI	Lazio	Roma	Roma	2012
F.lli Ratti	Piemonte	Alessandria	Tortona	2012
Kostner GmbH	Trentino Alto Adige	Bolzano	Varna	2012
Pucci Green Power	Lombardia	Lecco	Casatenovo	2016
DAM Carburanti S.a.s.	Lombardia	Pavia	Mortara	2015
Metano Senigallia S.r.l	Marche	Macerata	Corridonia	2016
Vulcangas	Marche	Pesaro-Urbino	Fano	2017
SETA (Azienda trasporto pubblico)	Emilia Romagna	Modena	Modena	2015

Table 33 - LNG satellite storages in Italy serving only C-LNG stations for road transport. Elaboration on REF-E data (2018)

It is expected that the situation won't change in the future, since Marseille-Fos is expected to continue playing an important role in LNG supply to Italy until national game changers will enter the game. This is particularly true if we consider that the Marseille-Fos terminal is going to be improved.

By 2021, in fact, Elengy intends to extend terminal bunkering activities by ensuring the supply of LNG to at least 100 units. Fosmax Lng then started a project to modify the quay that will allow the Fos Cavaou

terminal to host methane tankers with a capacity of less than 20,000 cubic meters which, after having supplied to Fos Cavaou, will be able to carry out their LNG bunkering operations in the port of Marseille-Fos and at other sites in the Mediterranean by supplying container ships, cruise ships or LNG-powered ferries. Overall, an investment of around 3 million euros is planned, financed 30% by the European Union, which will allow the following changes:

- the adaptation of the loading arms to allow the connection of smaller ships;
- new dock mooring systems to accommodate ships of 100 meters or more in length;
- boarding devices modified to take into account the lower height of the bridge of small scale LNG ships;
- the installation of a control valve on a second loading arm for the security of loading operations;
- The purchase of reserve load arms to ensure continuity of service
- during the maintenance phase even in the event of malfunction / breakdown.

The overall project at the terminal will not only allow to putting one or more refuelling vessel(s) in place that would be suitable for cruise ships and ferries as well as container ships, but also the rapid development of truck refuelling logistics that would initially serve ferries and continue to be an option should refuelling vessels be unavailable.

An important upgrading in the capacity of the tanker truck loading facility at the terminal is actually urgent if we consider the constant growth of its utilization rate, which as reported in the graph and table below, already reached 97% at the beginning of 2019.

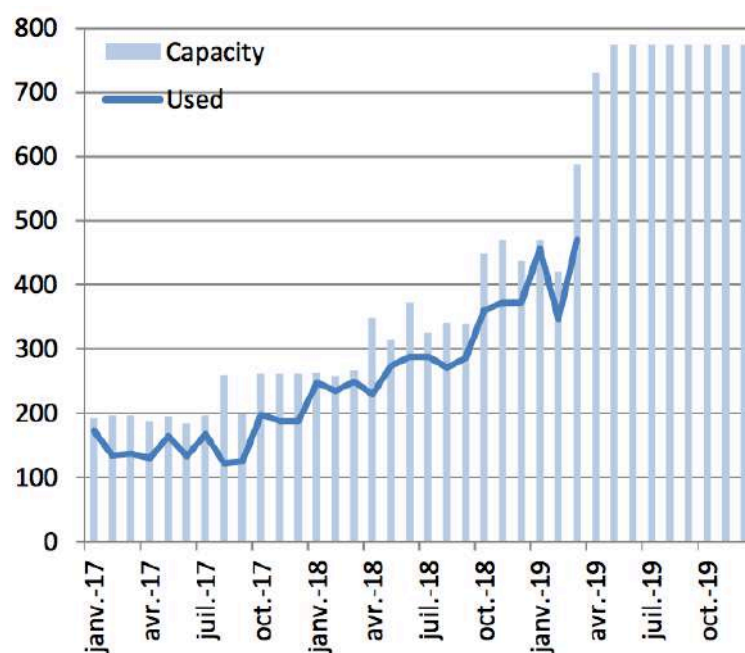


Figure 70 –Utilization rate's trend of the Fos Cavaou tanker truck loading facility. Source: Elengy company information

month-year	Fos Tonkin		
	Capacity	Used	% used
2013			
2014		18	2,7%
2015		397	34,6%
2016		918	57,4%
janv.-17	193	173	89,8%
févr.-17	196	134	68,5%
mars-17	196	137	70,0%
avr.-17	187	130	69,6%
mai-17	195	164	84,2%
juin-17	184	133	72,4%
juil.-17	196	168	85,8%
août-17	259	122	47,1%
sept.-17	198	125	63,1%
oct.-17	261	198	75,9%
nov.-17	261	188	72,0%
déc.-17	261	188	72,0%
janv.-18	262	248	94,5%
févr.-18	257	235	91,3%
mars-18	267	249	93,1%
avr.-18	348	229	65,8%
mai-18	313	274	87,5%
juin-18	372	288	77,4%
juil.-18	324	288	88,9%
août-18	341	271	79,4%
sept.-18	339	286	84,3%
oct.-18	449	360	80,2%
nov.-18	470	372	79,2%
déc.-18	437	373	85,4%
janv.-19	470	456	97,1%

Figure 71 –Utilization rate's values of the Fos Cavou tanker truck loading facility. Source: Elengy company information

With all that in mind, however, the overall cost for providing the Port of La Spezia of the LNG needed to cover the entire demand in the lower-case and even more in the higher-case scenario by road tankers seems prohibitive.

A more feasible option would be that of supplying by container ships or bulk ships (the latter type possibly being capable of ship-to-ship LNG transfer) at least to cover the consistent demand deriving from cruise ships, which represents the 80% and 70% of the entire demand in the Port of La Spezia in the lower-case and higher-case scenarios respectively. The remaining demand (about 7,9 and 26 thousands of tonnes for the lower-case and higher-case scenarios respectively) may be supplied by road transport on a regular basis (e.g. with seven tanker trucks or eight 40 foot ISO container per week in the lower-case scenario and twenty three tanker trucks or twenty seven 40 foot ISO container per week in the higher-case scenario).

6.4 Conclusions on cost and transit time simulations

As far as the economic viability and practicability of supplying LNG from international terminals is concerned (with Marseille-Fos at the helm), it can be concluded that the competitiveness of LNG end uses in Italy in general and in La Spezia in particular, is conditioned by the current supply logistics costs.

The downstream costs remain high even if they were reduced with the upgrading of the Fos Tonkin terminal which in 2017 covered almost all the needs eliminating the need to supply from other international terminals significantly more distant such as that of Barcelona.

It is expected that the infrastructural gap will start to be overcome with the entry into service of the first coastal terminals providing Small Scale Services in northern Italy, expected between 2020 and 2022.

6.5 Supply trips required to fulfil the whole La Spezia LNG demand from Panigaglia terminal

In this chapter an estimation of the number of trips necessary to supply the volumes of LNG which fulfil the estimated demand of La Spezia – for both scenarios, lower and higher – is reported. Estimation was made considering two hypothetical alternative vessels for supplying from the Panigaglia terminal, namely relatively small barges with capacity of 1,200 m³ or 2,200 m³.

Two different models of supply and distribution were conceived. In the first model, the whole demand for LNG is transported to a local storage, where it is later distributed to its final users (cruise ships, port vessels, etc.). In the second model, LNG is delivered to cruise ships by STS bunkering and to other users via intermediate storage. The demanded volumes per type of user and scenario are reported in the following table.

Users	Total annual demand (m ³)	
	Lower scenario	Lower scenario
Cruise ferries	70,200	140,400
Other users	17,529	57,788
Total	87,729	198,188

Table 34 - Total annual demand per scenario

An “all to storage” model requires 73 supply trips (between one and two per week) with a 1,200 m³ capacity barge to fulfil the entire demand in the lower scenario, 165 (3 per week or about every other day)

in the higher scenario. If a larger barge (2,200 m³ capacity) is employed, 40 trips (less than once a week) are necessary in the lower scenario, 90 (almost twice a week) in the higher one.

Ship capacity (m ³)	Number of trips	
	Lower	Higher
1,200	73	165
2,200	40	90

Table 35 - Number of annual supplying trips for entire demand ("all to storage" model) from Panigaglia

If LNG is bunkered to cruise ferries by ship-to-ship operations, 59 trips (once a week) are necessary for this specific use by means of a 1,200 m³ barge in a lower scenario, 117 (more than twice a week) in the higher one. Employing a larger barge (2,200 m³), 32 trips (about every other week) are necessary in the lower scenario, 64 (something more than once a week) in the higher one.

Ship capacity (m ³)	Number of trips	
	Lower	Higher
1,200	59	117
2,200	32	64

Table 36 - Number of annual supplying trips for ship-to-ship operations ("mixed" model) from Panigaglia

The remaining demand, to be served by means of an intermediate storage, requires 15 trips (about once a month) with a smaller barge (1,200 m³) in a lower scenario, 48 trips (about once a week) in a higher one. Considering a larger barge (2,200 m³), 8 trips (less than once a month) are necessary in the lower scenario, 26 (about two per month) in the higher one.

Ship capacity (m ³)	Number of trips	
	Lower	Higher
1,200	15	48
2,200	8	26

Table 37 - Number of annual supplying trips for non ship-to-ship operations ("mixed" model) from Panigaglia

For the 2 options considered some peculiar characteristics, from an operational point of view, can be derived or supposed referring to the technology solutions available and to the previously cited studies.

In particular, two factors concur to differentiate, along with capacity itself, one case from another: LNG transfer rates and transit time to La Spezia.

For the 1,200 m³ barge a loading rate between 30-450 m³/h can be supposed (therefore with a central value of about 200 m³/h), taking as reference the transfer capacity of the Titan LNG Flex-Fueler barge. For the 2,200 barge, a transfer rate of 500 m³/h can be assumed, as in the case of the Clean Jacksonville barge.

As for transit time, 40 minutes is the time estimated to go from Panigaglia to La Spezia port by sea (3.5 km).

Preliminary and final operations are estimated in the order of 30 minutes each, considering the assumption made in reference studies.

Operation	Type of ship	
	Barge 1,200 m ³	Barge 2,200 m ³
Preliminary operations	30 minutes	30 minutes
Loading rate	30-450 m ³ /h	500 m ³ /h
Transit time	40 minutes	40 minutes
Unloading/bunkering rate	30-450 m ³ /h	500 m ³ /h
Final operations	30 minutes	30 minutes

Table 38 - Operational time coefficients for considered supplying options

Applying the assumptions described above, the total operational time per trip and in the whole year (i.e. necessary to fulfil the entire demand) has been estimated for each case.

Operation	Operational time (hours)	
	Barge 1,200 m ³	Barge 2,200 m ³
Preliminary operations	0.5	0.5
Loading	6.0	4.4
Transit time	0.7	0.7
Unloading/bunkering	6.0	4.4
Final operations	0.5	0.5
Total operational time per trip - transit time included	13.7	10.5
Total n of supply trips - lower scenario	73	40
Total n of supply trips - higher scenario	165	90
Annual operational time - lower scenario	998	419
Annual operational time - higher scenario	2,255	942

Table 39 - Operational times for considered supplying options

The 2,200 m³ barge from Panigaglia option is instead the fastest one, with 10.5 hours, of which 4.4 for loading, 0.7 (40 minutes) for transit time and 4.4 for unloading.

In the entire year, 419 operational hours are required to deliver the lower scenario volumes to La Spezia from Panigaglia by barge with capacity of 2,200 m³.

Supplying from Panigaglia by 2,200 m³ barge requires the lowest transit time – which can be useful in case of urgent demand – and has relatively low investment costs, but lower transferred volumes per trip, bunkering rate and requires a higher number of trips during the year.

Barges (with or without self propulsion), given their limited dimensions, have an efficient/quick turnaround at loading/discharging ports (Boulougouris & Chrysinas, 2015).

7 Energy efficiency, GHGs and air pollutants emissions simulations for LNG supply from alternative sources

The need for new LNG transport infrastructure in the EU, Italy and the case study port, together with strict environmental policy targets justify studies of the environmental performance of alternative modes of LNG supply and transportation.

Such studies may have a purely scientific purposes, they may be focused on the local impacts of air pollutants, on the externalities produced, on the upstream side of the supply chain or with a LCA perspective.

It may be the case that investigations on the production of GHGs and air pollutants associated to the LNG supply for a certain node are aimed at providing useful elements to evaluate the suitability of supply pathways and, all in all, the competitiveness of the node itself.

With this overall purpose this study stemmed from the awareness that one of the principal reasons to explore LNG is its potential for environmental benefits. Nonetheless, considerable uncertainty remains about the net effects of LNG-fuelled vessels and other units on emissions. At issue are the upstream GHGs emissions (mainly CO₂ and methane) impacts of LNG, including the energy required to transport and handle the fuel as well as the leakage of natural gas into the atmosphere, which, together with the air pollutants (NO_x, SO_x, PM and hydrocarbons) are highly pathway-specific and should be taken into account when a supply chain for Small Scale LNG bunkering is to be set up.

7.1 *Selected sources of LNG supply envisaged in the simulations*

7.1.1 *Existing LNG sources depicting the “as is” scenario*

The first step was to shift the economic and operational considerations deriving from the simulations undertaken and described in Paragraph 5.2, towards the environmental dimension. Thus, the potential supply sources of LNG described in Paragraph 3.3 have been considered in the analysis to estimate the energy efficiency, GHGs and air pollutants emissions associated to LNG transport pathways from those supply sources, which are already existing and able to provide SS services, thus depicting what can be called the “as is scenario”, up to the particular delivery site of Terminal Ravano in the Port of La Spezia, as identified in Paragraph 3.2.


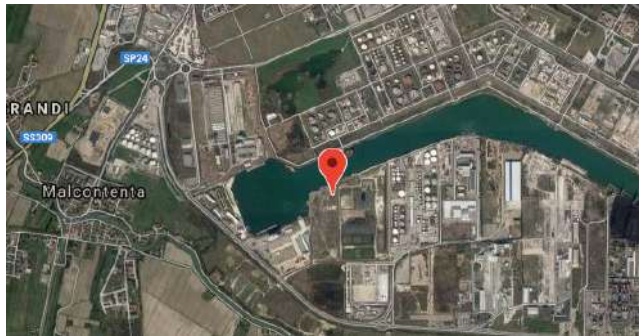

Table below recalls the sites and provides their coordinates used as input parameter for the simulations.

Terminal/site	Latitude	Longitude	Map view
Zeebrugge (1264 km by rail; 1206 km by truck)	51°35'30"N	3°22'24"E	
Rotterdam (1318 km by rail; 1262 km by truck)	51°97'11"N	4°06'88"E	
Barcelona (963 km by truck; 721 km by ship)	41°33'94"N	2°15'83"E	
Marseille (527 km by truck; 485 km by ship)	43°41'96"N	4°90'10"E	
Port of La Spezia final delivery site hypothesis (Terminal Ravano)	44°10'82"N	9°85'28"E	

7.1.2 Suitable planned LNG terminals depicting the “to be” scenario

The simulation has been then extended taking into consideration the Small Scale LNG Projects which are being build under the GAINN_IT Initiative’s umbrella and which are expected to enter into service in the next 2-3 years, thus depicting what can be called the “to be” scenario. Thus, the potential supply sources of LNG described in Paragraph 3.3, which are already existing and able to provide SS services, thus depicting what can be called the “as is scenario”,

Table below provides indications on the locations (and their coordinates used as input parameter for the simulations) of the Projects that have been considered in the analysis to estimate the energy efficiency, GHGs and air pollutants emissions associated to LNG transport pathways from those supply sources up to the particular delivery site of Terminal Ravano in the Port of La Spezia, as identified in Paragraph 3.2, and that is kept as final delivery site hypothesis.

Terminal/site	Latitude	Longitude	Map view
Livorno (99 km by rail; 94 km by truck, 75 km by ship)	43°56'48"N	10°30'18"E	
Venezia (367 km by rail; 356 km by truck)	45°43'71"N	12°22'36"E	
Oristano Terminal (474 km by ship)	39°86'08"N	8°55'90"E	

Besides those falling within the scope of the GAINN Projects considered above and described in the dedicated section of this document, there are currently other LNG Small Scale installations, as per table below, that are planned to be realized and which are currently undergoing the authorization process.

Location	Company	Storage capacity (m³)
<i>Ravenna</i>	Depositi Italiani GNL (Newco: PIR- Petrolifera Italo Rumena/Edison)	20.000
<i>Oristano</i>	IVI Petrolifera S.p.A.	9.000
<i>Oristano</i>	Edison S.p.A.	10.000
<i>Cagliari</i>	ISGAS ENERGIT Multiutilites S.p.A.	22.000
<i>Porto Torres</i>	Consorzio Industriale Provinciale Sassari	10.000

Table 40 – Planned LNG SS Project under authorization, not considered in the simulations of the “to be scenario”. Elaboration on MinAmb public data and documents.

A brief description of the planned projects is hereby given to provide elements useful to envisage the future assets the LNG Small Scale (SS) infrastructure system in Italy will count on.

LNG SS plant in Ravenna

Project’s main features and process data

- Storage of 20.000 m³ of LNG (1 LNG cryogenic tank)
Occupied area 23,000 m² (quay of 280 meters and draft around 8 m)
- The distribution of LNG from the storage tank to the outside envisages:
 - refueling of HDVs stations by road tankers (useful capacity of about 40 m³);
 - bunkering by feeder vessels (load capacity between 1,000 and 4,000 m³).
- Maximum loading capacity of the terminal: 2. 000 m³ / h
- Maximum bunker vessel loading capacity: 500 m³ / h
- Maximum loading capacity of tank trucks: 60 m³ / h
- Number of bays for loading tankers: 5 + 1



Figure 72 - Overview of the building site of the LNG SS Plant in Ravenna: in blue the Bunge Italia plant, in green the Teodora plant of ENEL Produzione and in red the intervention area. MISE DG SAIE (2018)



Figure 73 - LNG storage tank and loading arms of the LNG SS Plant in Ravenna. MISE DG SAIE (2018)

Edison project in the southern channel of the port of Oristano

Project's main features and process data

- Storage of 12,000 m³ of LNG
- 7 LNG cryogenic tanks of about 1,700 m³ each
- Maximum annual handling capacity (rotation index) 520,000 m³
- Supplied with small gas tankers (capacity 7,500 and 27,500 m³)
- Distribution by road tankers (terminal to truck - 4 loading bays for 40 trucks / day) and barges (terminal to ship) with a minimum capacity of 1,000 m³



Figure 74 - Rendering of the Edison project in the southern channel of the port of Oristano. MISE DG SAIE (2018)

Mini regasifier and storage ISGAS project in the Port of Cagliari

Project's main features and process data

- Storage of 22,608 m³ of LNG (18 LNG cryogenic tanks of 1.226 m³)
- Supplied with small gas tankers (capacity 7,500 and 20,000 m³)
- Regasification plant that supplies current Cagliari distribution networks
- LNG distribution through tankers (one loading bay) and bunkering (ship to ship, truck to ship, terminal to ship via pipeline)

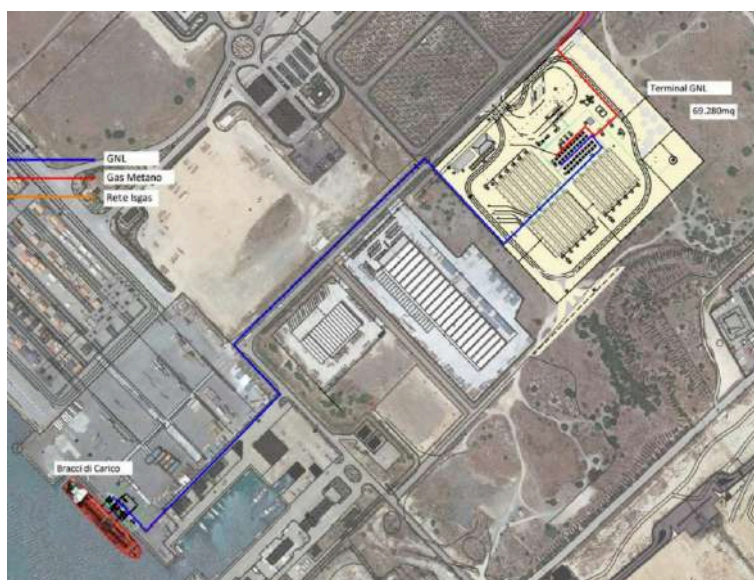


Figure 75 – Layout scheme of the ISGAS project in the Port of Cagliari. MISE DG SAIE (2018)

LNG SS Project of IVI Petrolifera in Oristano

Project's main features and process data

- Storage of 9,000 m³ of LNG at Santa Giusta - Oristano
- The maximum annual volumes stored will be equal to 60,000 m³ of LNG
- 9 cryogenic LNG tanks of 1,000 m³ each
- Supplied by small gas tankers (capacity from 4.000 and 5.000 m³)
- Distribution by road tankers of a capacity of approximately 50 m³ and by means of barges with a capacity of 500m³

The stage of design is such that at present no renderings or charts depicting the planned Project are available.

Commercially active since 2013 off the coast of Livorno, the FSRU (Floating Storage Regasification Unit) OLT Offshore LNG Toscana plant was born from the conversion of a LNG tanker - the "Golar Frost" - into the world's first floating regasification terminal permanently moored offshore.

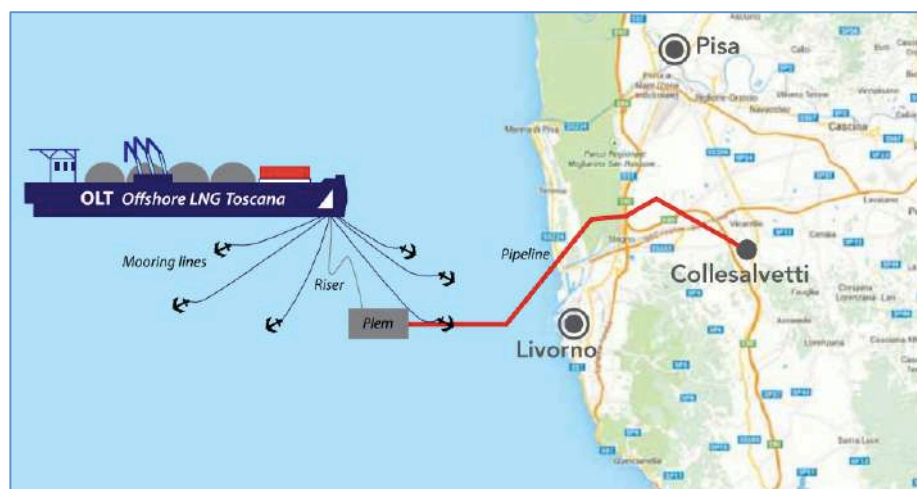


Figure 76 – FRSU Toscana Offshore map view. OLT (2018)



Figure 77 – Picture of the FRSU Toscana Offshore plant. OLT (2018)

The activity carried out by the terminal consists in the storage and regasification of liquefied natural gas.

The natural gas is therefore received in the liquid state, using tankers, stored in cryogenic tanks at almost ambient pressure and at a temperature of -160°C , regasified and sent to the gas pipeline on the ground through the subsea pipeline. The main process plants can be summarized in the following phases:

- approaching and mooring of LNG carriers with the aid of suitable tugs;
- transfer from the methane tankers and loading the LNG (liquefied natural gas) on board the Terminal through the use of the 4 loading arms;
- storage in the 4 MOSS tanks (unit volume of approximately $34,275\text{ m}^3$, and overall approximately $137,100\text{ m}^3$ gross) and pumping of LNG to the regasification plant;
- recovery of the BOG (Boil off gas: vapors produced by the storage tanks) through the conveyance towards a manifold common to all the tanks and then sent to the supplying vessel, to the boilers or to the send out system;
- LNG vaporization using 3 vaporizers that use sea water as a heat source and propane as an intermediate heating fluid between sea water and LNG;
- conveyance of natural gas to the pipeline;
- methane tanker unmooring.

With a view to providing additional services for Small Scale bunkering, the terminal could be adapted to provide for the possibility of loading LNG on small LNG bunkering vessels, with a length between 60 and 110 meters, currently corresponding to a load capacity of between $1,000\text{ m}^3$ and $7,500\text{ m}^3$ and a loading rate between $250\text{ m}^3/\text{h}$ $900\text{ m}^3/\text{h}$.

The upgradings needed to provide this new service would relate to the left side of the plant, where the

main elements for loading and unloading are already present, limited (in the order of 5 Mio) and could be carried out in reduced time once the necessary authorizations have been obtained. In March 2019 the EIA procedure started at the Italian Ministry of the Environment.

It is to be noted that such planned projects have not been taken into consideration in the simulations because of two main reasons:

1. There is no clear evidence about the final delivery date of the installations, thus they may be come into operation far later than those funded under the GAINN-IT Initiative;
2. The planned locations of the interventions are geographically overlapped with those considered for the simulations (in the Tyrrhenian Basin, the already under construction Higas' LNG plant would be forerunner respect to the other planned in Oristano, Cagliari and Porto Torres, whereas in the Adriatic Basin, the LNG terminal in Venice will anticipate the realization of the one to be realized in Ravenna).

7.2 Simulation methodology using EcoTransit tool

7.2.1 EcoTransit as a supportive tool for decision making in the transport sector

Already used by several companies of all sizes all over Europe and as tool at the basis of the study methodology of a number of scientific papers, EcoTransIT is as pertinent to the study of large-scale flows as it is to the analysis of an individual movement, and for its wide array of applications is being increasingly used by company managers, logistics operators, progressive transport planners, political decision makers, customers, NGOs and all stakeholders who are interested in calculating the environmental impact of freight transport on specific routes.

EcoTransIT World (ETW), meaning Ecological Transport Information Tool – worldwide, is an open access online application, which shows the environmental impact of freight transport for any route in the world and any transport mode. More than showing the impact of a single shipment it compares different transport modes or logistical chains with each other thus making evident, which is the solution with the lowest environmental impact.

Thus, EcoTransIT is a decision-making tool that helps to optimise the logistical chains and networks of a company's distribution activity and deliver reliable data for external communication.

This chapter gives an overview of basic definitions, assumptions and calculation rules for freight transport used in ETW. The focus will be on the common rules for all transport modes and the basic differences between them. Detailed data and special rules for each transport mode are described in chapter 6. In general, the calculation rules and methodologies used by ETW are in accordance with the European standard EN 16258.

7.2.2 Main factors of influence on energy and emissions of freight transport

The energy consumption and emissions of freight transport depends on various factors. Each transport mode has special properties and physical conditions. The following aspects are of general importance for all modes of transport:

- Vehicle/vessel type (e.g. ship type, freight or passenger aircraft), size and weight, payload capacity, motor concept, energy, transmission,
- Capacity utilisation (load factor, empty trips),
- Cargo specification (mass limited, volume-limited, general cargo, pallets, container),
- Driving conditions: number of stops, speed, acceleration, air/water resistance,
- Traffic route: road category, rail or waterway class, curves, gradient, flight distance,
- Total weight of freight and
- Transport distance.

In ETW, parameters with high influence on energy consumption and emissions can be changed in the extended input mode by the user. Some other parameters (particularly the transport distance) are selected by the routing system. All other parameters, which are either less important or cannot be quantified easily (e.g. weather conditions, traffic density and traffic jam, number of stops) are included in the average environmental key figures. The following table gives an overview on the relevant parameters and their handling (standard input mode, extended input mode, routing). Independent of the possibility that user can change values ETW includes so called standard values or default values for all parameters. The default values used by ETW will be presented in the next chapters. All default values are chosen in such a way, that they are in line with the European standard EN 16258. Or in other words: if users calculate energy consumption and CO₂e emissions based on default values included in ETW the results fulfil always the requirements of EN 16258.

Sector	Parameter	Road	Rail	Sea ship	Inland Ship	Aircraft
Vehicle, Vessel	Type, size, payload capacity	E	E	E	E	E
	Drive, energy	A	E	A	A	A
	Technical and emission standard	E	A	A	E	A
Traffic route	Road category, waterway class	R			R	
	Gradient, water/wind resistance	A	A	A	A	A
Driving Conditions	Speed	A	A	E	A	A
	No. of stops, acceleration	A	A	A	A	A
	Length of LTO/cruise cycle					R
Transport Logistic	Load factor	E	E	E	E	E
	Empty trips	E	E	E	E	E
	Cargo specification	S	S	S	S	S
	Intermodal transfer	E	E	E	E	E
	Trade-lane specific vessels			R		
Transport Work	Cargo mass	S	S	S	S	S
	Distance travelled	R	R	R	R	R
Remarks:						
A = included in average figures,						
S = selection of different categories or values possible in the standard input mode,						
E = selection of different categories or values possible in the extended input mode,						
R = selection by routing algorithm,						
empty = not relevant						

Table 41 – Classification and mode (standard, extended, routing) of main influence factors on energy consumption and emissions in ETW

7.2.3 Basic rules for energy consumption calculations

In ETW the total energy consumption and emissions of each transport mode are calculated for vehicle usage (TTW) and the upstream process (WTT). Thus, several calculation steps are necessary:

- Final energy consumption (TTW energy consumption) per net tonne-km;
- Energy related vehicle emissions per net tonne km (TTW);
- Combustion related vehicle emissions per net tonne km (TTW);
- Energy consumption and emission factors for upstream process per net tonne km (WTT) ;
- Total energy consumption and total emissions per transport (WTT).
- More information about special calculation rules and the database are given in Chapter 6 of the

To our aims, the total energy consumption and emissions of transport (WTW) have been considered.

The principal calculation rule for the calculation of vehicle emissions is

WTW energy consumption or emissions per transport

=

*Transport Distance * mass of freight transported * (TTW energy consumption or vehicle emissions per net tonne km + WTT energy consumption or emissions per net tonne km)*

The corresponding formulas are:

$$EMT_i = D_i * M * (EMV_{tkm,i} + EMU_{tkm,i})$$

$$ECT_i = D_i * M * (ECF_{tkm,i} + ECU_{tkm,i})$$

Abbr.	Definition	Unit
EMT _i	WTW emissions of transport	[kg]
ECT _i	WTW energy consumption of transport	[MJ]
D _i	Distance of transport performed for each energy carrier i	[km]
M	Mass of freight transported	[net tonne]
EMV _{tkm,i}	TTW Vehicle emissions for each energy carrier i	[g/tkm]
ECF _{tkm,i}	TTW energy consumption for each energy carrier i	[MJ/tkm]
EMU _{tkm,i}	WTT (upstream) emission factors for each energy carrier i	[g/tkm]
ECU _{tkm,i}	WTT (upstream) energy consumption for each energy carrier i	[MJ/tkm]
i	Index for energy carrier (e.g. diesel, electricity, HS)	

Table 42 – Factors and indexes for the EcoTransit's calculation of the total energy consumption

It is then to be noted that:

- Transport distance is a result of the routing algorithm of ETW
- WTW energy consumption and emissions also depend on routing (e.g. road categories, electrification of railway line, gradient, distance for airplanes). This correlation is not shown as variable index in the formulas due to better readability.
- Mass of freight is either directly given by the client or recalculated from number of TEU, if TEU is selected as input parameter in the extended input mode of ETW.

- Using the formula described above for the calculation of WTW energy consumption and WTW CO₂ equivalent emissions of transport services fulfils the requirements of EN 16258. Therefore, the methodology is in accordance with the European standard.

7.2.4 Methodological considerations related to road transport simulations

LNG can be transported in specialized cryogenic semi-trailers, or through LNG ISO containers, both keeping a low temperature of liquefied gas during transport.

A typical semi-trailers has a capacity of 18 tonnes, which after regasification makes possible 25,600 Nm³ of natural gas in the gaseous form.

The trailers consist of a horizontal vacuum-insulated tank composed of an 'inner' pressure vessel and a structural frame/vacuum vessel 'outer' jacket. The outer jacket is made from lightweight, thin-gauge carbon and stainless steel, and the inner vessel is a 70 psig pressure vessel made from SA240 T-304 stainless steel.

The control piping and instruments are located in a spacious, wrap-around style, rear piping cabinet. Maximum use is made of the available space at the end of the trailer to make the control piping easy to operate, access and maintain. Use of drop-down piping allows for waist-high connection of the fill connectors (fill/drain and vapour return).

It is to be noted that although the advantages brought in terms of LNG capacity, the flexibility of this solution is limited, considering that does not allow for intermodal LNG transport.

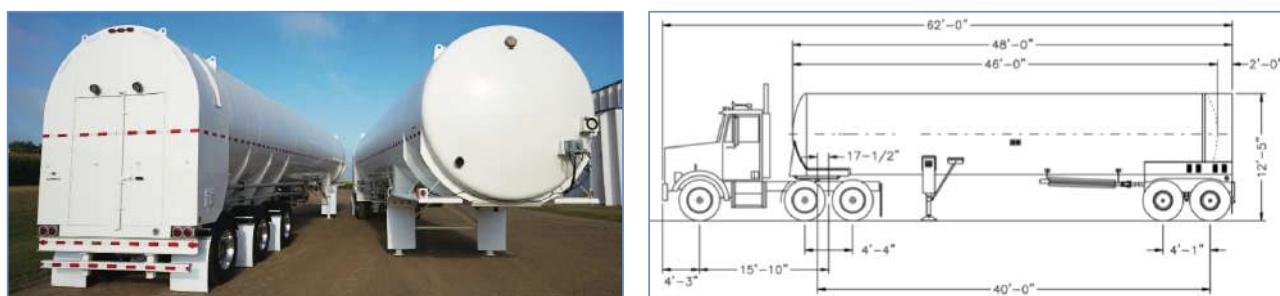


Figure 78 – Typical LNG semitrailers available on the market. Chart Industries company information

Model	ST-16300
Gross Capacity	16,300 gal / 61,702 ltrs
LNG Capacity (at 70 psig / 4.826 barg)	50,400 lbs / 22,861 kg
Maximum Allowable Working Pressure	70 psig / 4.83 barg
Length (overall)	53 ft / 16.2 m
Width (overall)	8 ft 6 in / 2.6 m
Height	12 ft 10 in / 3.91 m
Weight	33,000 lbs / 14,966 kg
Design Codes	ASME Section VIII Division 1
Axle Configuration	Tri

Table 43 – Technical specifications of a typical LNG road tanker. Chart Industries company information

On the other side, typical LNG ISO containers available on the market that could be used in intermodal supply chain can be 20 or 40 ft units. Chart Industries is one of the leading manufacturers of ISO containers and these simulations take their product as a reference because of their widespread use.



Figure 79 – Chart’s 20’ ft (left) and 40 ft (right) intermodal LNG ISO-containers. Chart Industries company information

A Chart ISO 20 foot LNG container will have a tare weight of 7,600kg and a capacity of 20,370 liters (around 8,6 tonnes) of LNG at a maximum pressure of 10 bar. The 20 foot container will be able to keep the LNG in a liquid state for up to 80 days. A Chart ISO 40 foot LNG container will have a tare weight of 11,500kg with a capacity of 43,500 liters (around 18,5 tonnes) of LNG at a maximum pressure of 10 bar. The 40 foot container will be able to keep the LNG in a liquid state for up to 70 days depending on the ambient air temperature. The technical specifications of the most common version of these units are illustrated below.

To the purpose of this study, both 20ft and 40ft ISO-container units have been considered.

20 ft. CONTAINER - EN										
Code	Model	Service	Gross Water Capacity (liters)	MAWP*	Lenght (mm)	Width (mm)	Height (mm)	Tare Weight (kg)	Max. Gross Weight (kg)	Hold Time LOX (days)
EN, ADR IMDG, RID, ISO, TC	ICC-20-P-10	LIN, LOX,	20 370	10 bar	6 058	2 438	2 591	6 625	36 000	79
	ICC-20-P-18	LAR, LNG,	20 160	18 bar				8 075		102
	ICC-20-P-24	Ethane, Ethylene, N ₂ O	20 080	24 bar				9 025		114

40 ft. CONTAINER - EN or ASME/DOT										
Code	Model	Service	Gross Water Capacity (liters)	MAWP*	Lenght (mm)	Width (mm)	Height (mm)	Tare Weight (kg)	Max. Gross Weight (kg)	Hold Time LNG (days)
EN, ADR IMDG, RID, ISO, TC	TSV-43-PB-10	LNG, Ethane, Ethylene	43 500	10 bar	12 192	2 438	2 591	11 500	34 000	132
ASME/DOT ADR, IMDG, RID, ISO, TC	TSV-115-PB-100	LNG, Ethane, Ethylene	43 500	100 PSI	12 192	2 438	2 591	11 500	34 000	109

Table 44 – Chart's intermodal ISO-containers specifications. Chart Industries company information

Regarding the type of trucks used for the transportation of the LNG cargo envisaged within the simulations, it is noted that worldwide the vast majority of the trucks uses diesel as fuel. Due to the potential emission reductions and lower fuel costs some fleet managers invested into alternative fuels recently. In 2014 around 200,000 heavy or medium-heavy trucks in Europe (most of them in Eastern Europe) and 350,000 heavy or medium-heavy trucks in China were using CNG or LNG according to the natural gas vehicle association (NGVA).

LNG trucks are common for heavy trucks (>26 t GW), which is the case investigated here, assuming that truck trailers would transport the LNG cargo stored in cryogenic ISO containers with an overall gross weight at full capacity of around 36.000 kg.

Vehicle Type		full 100%	average 50%	empty 0%
Energy Consumption (MJ/km)				
Truck Euro VI	>3,5-7,5t	5.1	4.9	4.7
	>7,5-12t	7.1	6.6	6.1
	>12-20t	8.5	7.8	7.0
	>20-26t	10.6	9.1	7.8
	>26-40t	13.3	10.9	8.2
	>44-60t	19.0	14.5	9.9
NOx-Emissions (g/km)				
Truck >26-40t	Euro-I	10.49	8.74	6.78
	Euro-II	10.71	9.08	7.21
	Euro-III	8.10	6.45	5.05
	Euro-IV	3.75	3.15	3.16
	Euro-V	2.39	2.09	2.19
	Euro-VI	0.27	0.25	0.35
NMHC-Emissions (g/km)				
Truck >26-40t	Euro-I	0.461	0.423	0.435
	Euro-II	0.297	0.289	0.289
	Euro-III	0.263	0.266	0.274
	Euro-IV	0.030	0.025	0.022
	Euro-V	0.039	0.035	0.033
	Euro-VI	0.025	0.024	0.023
PM-Emissions (g/km)				
Truck >26-40t	Euro-I	0.322	0.264	0.238
	Euro-II	0.163	0.141	0.122
	Euro-III	0.146	0.139	0.135
	Euro-IV	0.036	0.033	0.031
	Euro-V	0.038	0.035	0.033
	Euro-VI	0.004	0.003	0.003

Table 45 – Energy consumption and emissions (TTW) of selected trucks with different load factors in Europe. Source: EcoTransit methodology based on Handbook Emission Factors for Road Transport 3.2 (INFRAS 2014).

CNG and LNG trucks have higher specific energy consumptions than diesel, mainly due to the lower energy efficiency of the stoichiometric spark ignition engine used for most gas trucks. Based on a review of literature and fleet park operator's data a 24% higher energy consumption compared to diesel trucks is assumed. Dual fuel trucks use compression ignition (diesel) engines and are therefore assumed to have the same fuel efficiency than diesel trucks. The average ratio of natural gas (LNG) to diesel in energy consumption of dual fuel trucks for ETW is 60:40, based EcoTransit assumptions.

Vehicle Type (fuel, size, emission standard)	EC	NOx	NMHC	PM
CNG, all size classes, Euro V	+24%	similar		Euro VI
CNG, all size classes, Euro VI	+24%	similar		
LNG, all size classes, Euro V	+24%	similar		Euro VI
LNG, all size classes, Euro VI	+24%	similar		
Dual Fuel (LNG/Diesel), all size classes, Euro V	similar			
Electric (Battery), all size classes	-44%	-100% (no tailpipe emissions)		
Source: (DLR et al. 2015), ifeu assumptions				

Table 46 – TTW emission factors of alternative fuel compared to diesel trucks

Less information is available on real world air pollutant emissions (NOx, NMHC and PM) of gas trucks. It is assumed that the emissions are similar to the diesel trucks, except that Euro V CNG and LNG trucks have lower PM emissions, which are similar to Euro VI diesel trucks. This is due to the fact that spark ignited gas engines have very low PM emissions, even without using particle filter. The SOx emissions depend on the sulphur content, which is assumed to be 3.5 ppm and therefore lower than for diesel.

It has to be mentioned that the given assumptions provide only a rough picture and include uncertainties which can be hardly quantified at the moment. With increasing market entrance of alternative fuel trucks and availability of measurement data the emission factors should be reviewed.

Furthermore, the processes for energy generation greatly differ for the different truck types. These emissions have to be included for an adequate comparison of emissions, especially for electric trucks. Emissions from vehicle construction are not yet within the scope of EcoTransIT, but can have a relevant share of lifecycle emissions (i.e. for batteries).

[Considerations on energy consumption and GHGs related to LNG road transport](#)

The energy and GHG conversion factors (e.g. MJ or kg CO₂ equivalent per litre diesel) for the EcoTransIT World calculation are taken from the appendix A of the standard EN 16258 without changes. For European trucks a biofuel share of 5 % is considered for diesel.

The specific conversion factors used are documented within the EcoTransit methodology report and are recapped hereinafter in table.

Fuel type description	density (d)	Energy factor		CO2e-factor	
	kg/l	MJ/kg	WTW	kgCO ₂ e/kg	
		TTW		TTW	WTW
Gasoline	0.745	43.2	50.5	3.25	3.86
Ethanol	0.794	26.8	65.7	0.08	1.56
Diesel	0.832	43.1	51.3	3.21	3.9
Bio-diesel	0.890	36.8	76.9	0.08	2.16
Liquefied Petroleum Gas (LPG)	0.550	46.0	51.5	3.10	3.46
Compressed Natural Gas (CNG)	x	45.1	50.5	2.68	3.07
Aviation Gasoline (AvGas)	0.800	44.3	51.8	3.13	3.76
Jet Gasoline (Jet B)	0.800	44.3	51.8	3.13	3.76
Jet Kerosene (Jet A1 and Jet A)	0.800	44.1	52.5	3.18	3.88
Heavy Fuel Oil (HFO)	0.970	40.5	44.1	3.15	3.41
Marine Diesel Oil (MDO)	0.900	43.0	51.2	3.24	3.92
Marine Gas Oil (MGO)	0.890	43.0	51.2	3.24	3.92
Liquefied natural gas (LNG)* - not EN 16258	x	45.1	56.2	2.68	3.62

* The EN 16258 does not contain default values for liquefied natural gas (LNG). For EcoTransIT, similar TTW values as for CNG are assumed (both fuels contain mainly methane). The WTT values base on ifeu / INFRAS / LBST 2015. The values are higher than for CNG due to higher energy intensity, especially for liquefaction.

Table 47 – EN 16258 default conversion factors for fuels and gases

Fuel type description	CO2-factor kgCO ₂ /kg	
	TTW	WTW
Gasoline	3.17	3.78
Ethanol	0.00	0.75
Diesel	3.16	3.84
Bio-diesel	0.00	0.62
Liquefied Petroleum Gas (LPG)	3.02	3.37
Compressed Natural Gas (CNG)	2.54	2.78
Aviation Gasoline (AvGas)	3.10	3.74
Jet Gasoline (Jet B)	3.10	3.74
Jet Kerosene (Jet A1 and Jet A)	3.15	3.85
Heavy Fuel Oil (HFO)	3.11	3.38
Marine Diesel Oil (MDO)	3.21	3.89
Marine Gas Oil (MGO)	3.21	3.89


Table 48 – Default values for carbon dioxide consistent with EN 16258

Considerations on carbon emissions and air pollutants related to LNG road transport

The European standard EN 16258 does not contain methodological guidelines for the calculation of CO₂ and air pollutants. For comparability with the results for energy consumption and GHG emissions the calculation of CO₂ and air pollutants is based on the same methodology as the European standard. Further information about the calculation approach used by EcoTransit for CO₂ and air pollutants can be found in the scientific methodology report.

As far as the parameters adopted as input for the road transport calculations on the EcoTransit Tool in its extended version, as shown in figure below, these have been differentiated according to the fuel used to transport of the LNG cargo.

Input parameters for road LNG transport calculations

CALCULATION PARAMETERS	
Weight:	36 Bulk and Unit Load (Tonnes)
t/TEU:	14.5
Define handling:	-
Change	
Transport service TS 1	
Origin:	51.353000000000016 / 3.222710407409636
	Class: 26-40 t, EURO 6
	Fuel type: diesel
	LF: 90.0%
	ETF: 60.0%
Destination:	44.108295628657885 / 9.852955746032649


CALCULATION PARAMETERS	
Weight:	36 Bulk and Unit Load (Tonnes)
t/TEU:	14.5
Define handling:	-
Change	
Transport service TS 1	
Origin:	51.353000000000016 / 3.222710407409636
	Class: 26-40 t, EURO 6
	Fuel type: lng
	LF: 90.0%
	ETF: 60.0%
Destination:	44.108295628657885 / 9.852955746032649

Figure 80 – Calculation parameters used as input for EcoTransit Tool-based simulations related to LNG road transport by diesel truck (left) and LNG truck (right)

Explanation of the parameters is given as follows:

- Weight: a total load of 36 tonnes has been envisaged, being compatible with both 20 and 40 ft ISO-containers at full capacity;
- t/TEU: the value of 14,5 of tonnes per containerized unit is set automatically for heavy cargoes which has been selected (however, this has not any incidence on the overall calculations);
- Handling type: being it a liquid, but at cryogenic state, the handling was kept undefined as not present among the options (however, also this has not any incidence on the overall calculations);
- Origin and destination: geographical coordinates of the supply terminals and of Terminal Ravano as delivery destination (followed by map waypoint's selection on the tool's interface) have been inserted;
- Class: the assumption was that of considering an ADR tanker truck with a total laden weight exceeding 26 tons as it was for the cost and transit time simulations. Therefore the interval of 26-40 tonnes of cargo capacity has been selected; EURO6 was selected in both cases as it is assumed that the trucks meet the most stringent standards as far as air quality is concerned;
- Fuel Type: a diesel Euro 6 Loading Factor (LF): considering the overall weight of 36 tonnes for the transported ISO-container unit, and assuming 40t as the maximum loading factor, a percentage of 90 has been applied;
- Loading Factor (LF): considering the overall weight of 36 tonnes for the transported ISO-container unit, and assuming 40t as the maximum loading factor, a percentage of 90 has been applied;
- Empty Trip Factor (ETF): this standard parameters is automatically suggested by the tool based on the type of transport service selected and has been therefore kept unchanged.

7.2.5 Methodological considerations related to rail transport simulations

Rail transportation of LNG by ISO container has been proposed for Sweden and Finland. Swedish railcar manufacturer Kiruna Wagon has developed plans for a railcar concept suitable for LNG ISO containers. Ragner's 2014 report noted, as in earlier Great Lakes Maritime Research Institute (GLMRI) studies, that a key factor in developing LNG transportation nodes will be the multiple user groups driving the market. The Ragner study cited possible containerized LNG users belonging to the following industry groups:

- Forest industries
- Mining industries
- Steel industries

- Aluminum industries
- Foundries
- (Chemical) process industries
- Ports
- Filling stations for heavy duty trucks”²⁸

LNG bulk tank cars would have to be designed, tested and approved before any shipment could take place. If there were sufficient long-term demand that provided railroads with a viable return on investment then LNG bulk rail cars would be considered. In addition to safe operations factors such as distance, demand and economies of scale will determine if the LNG is best shipped by bulk tank car or by ISO Container. Table 3 captures many of the considerations that will be key factors in selecting bulk tank cars or container.

ISO LNG container by rail	LNG rail tank car
Small volume units.	Large volume rail cars.
Transport by rail approved by special permit from Federal Railway Administration. Some states may have a regulatory impact on the transportation of LNG.	No rail car has yet been designed, tested, and approved for use in the U.S.
Containers can be drayed by truck from between rail terminals and liquefaction plants.	Rail sidings to LNG liquefaction plants is required for loading of LNG rail cars.
Alternative truck delivery may be an option if there is rail network failure.	Rail network closure stops transportation of rail cars.
A loading/unloading system is required at terminals. Top picks, cranes or straddle carriers. Additional handling increases risk of accidents.	No special off track equipment required to load.
Containers can be used for storage at the end users location(s).	Rail car could be used for storage by customer if approved rail sidings are available.
Containers are approved and can be transferred to marine and truck modes as well as rail.	Unable to transfer rail cars to truck. Approval would be required for transfer to marine car ferries.
Containers carry less than a dedicated LNG truck. The rail ISO LNG containers require less highway mileage than all truck transport for the same movement of cargo. This means less traffic congestion, lower environmental pollution and lower costs.	Tank rail cars remove the equivalent of two and half or three trucks off the highway. This means less traffic congestion, lower environmental pollution and lower costs.

Table 49 – Comparison of rail transport of ISO LNG containers and LNG rail tank cars. Source: Stewart and Tada (2016)

Rail transportation of LNG ISO containers also provides expanded options for the siting of new liquefaction plants. The plants could be built in less populated areas where suitable gas, power, road and rail service is available. The ISO LNG containers also provide increased opportunities for LNG to be supplied to vessels. There may also be the option, (that was not explored in this study), of placing ISO LNG containers on barges that can provide mid-stream refuelling from the ISO LNG containers to vessels alongside. Stacking of the

²⁸ Ragnar. Martin, “Rail transportation of liquid methane in Sweden and Finland”, SGC Rapport 2014:295, Svenskt Gastekniskt Center AB, Malmö, 2014. www.sgc.se

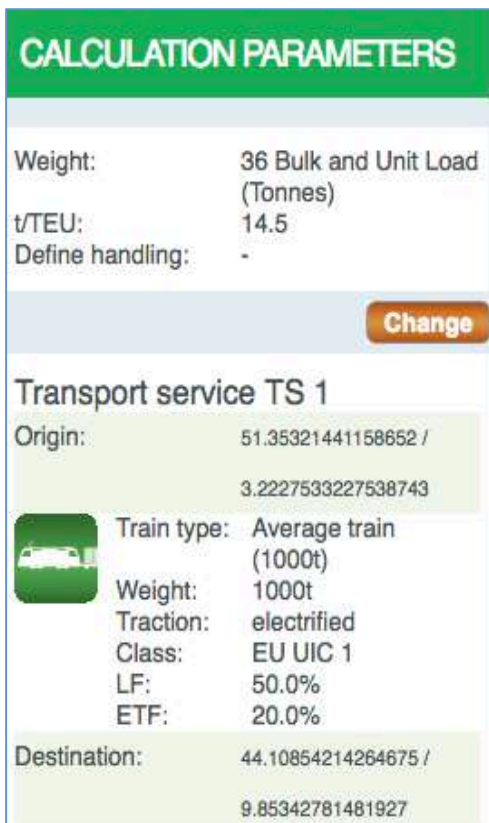
ISO LNG containers is done aboard ship and should be possible on rail cars and where necessary in terminals. This would allow for greater economies of scale.


Regarding the methodology for the calculation of GHG emissions, it is to be noted that for train transports the European standard does not contain specific energy and GHG conversion factors. Therefore EcoTransIT uses own country specific conversion factors which are documented within the methodology report.

[Input parameters for rail LNG transport calculations](#)

As far as the parameters adopted as input for the rail transport calculations on the EcoTransit Tool in its extended version, as shown in figure below, the same cargo weight for road transport has been adopted, as also in this case the LNG cargo is supposed to be transported contained in ISO cryogenic units. Also in this case, for origin and destination the geographical coordinates of the supply terminals and of Terminal Ravano as delivery destination (followed by map waypoint's selection on the tool's interface) have been inserted.

The other input parameters are the following:



CALCULATION PARAMETERS	
Weight:	36 Bulk and Unit Load (Tonnes)
t/TEU:	14.5
Define handling:	-
Change	
Transport service TS 1	
Origin:	51.35321441158652 / 3.2227533227538743
 Train type:	Average train (1000t)
Weight:	1000t
Traction:	electrified
Class:	EU UIC 1
LF:	50.0%
ETF:	20.0%
Destination:	44.10854214264675 / 9.85342781481927

- Train type and traction: an average electrified train of 1000 tonnes has been envisaged, being a standard train type over different distances in Europe;
- Class: In ETW a typical average wagon is defined based on wagon class Type 1 UIC 571-2 (ordinary class, four axles, short, empty weight 23 tonnes);
- Loading Factor (LF): since the payload capacity for that type of wagon is of 61 tonnes, as defined by railway experts of the EcoTransIT World Initiative (EWI), the resulting maximum total wagon weight being 84 tonnes and the maximum axle weight 21 tonnes, the loading factor of about 50% was considered appropriate;
- Empty Trip Factor (ETF): this standard parameters is automatically suggested by the tool based on the type of transport service and therefore kept unchanged.

Figure 81 – Calculation parameters used as input for EcoTransit Tool-based simulations related to LNG railway transport

7.2.6 Methodological considerations related to waterborne transport simulations

The sea transport emission factors in ETW are largely based on the findings of the Third Greenhouse Gas study of the International Maritime Organization. Basically, fuel consumption and emission factors for main engine, auxiliary engine and boiler were derived in a bottom-up approach from IMO data for individual ship categories and size classes and validated using worldwide fuel consumption and CO₂ emissions for 2012 from /IMO 2015/. These factors were then aggregated to the vessel types and size classes available in the Extended input mode of ETW

Vessel types (and cargo handling)	Trade and Vessel category names	Aggregated size class
GC	Coastal	< 5,000 DWT
BC / GC (dry)	Feeder	5,000 – 15,000 DWT
BC / GC (dry)	Handysize	15,000 – 35,000 DWT
BC (dry)	Handymax	35,000 – 60,000 DWT
BC (dry)	Panamax	60,000 – 80,000 DWT
BC (dry)	Aframax	80,000 – 120,000 DWT
BC (dry)	Suezmax	120,000 – 200,000 DWT
BC (liquid)	Feeder	5,000 – 15,000 DWT
BC (liquid)	Handysize	15,000 – 35,000 DWT
BC (liquid)	Handymax	35,000 – 60,000 DWT
BC (liquid)	Panamax	60,000 – 80,000 DWT
BC (liquid)	Aframax	80,000 – 120,000 DWT
BC (liquid)	Suezmax	120,000 – 200,000 DWT
BC (liquid)	VLCC (+)	> 200,000 DWT
CC	Feeder	<1,000 TEU
CC	like Handysize	1,000 – 2,000 TEU
CC	EU SECA like Handysize	1,000 – 2,000 TEU
CC	like Handymax	2,000 – 3,500 TEU
CC	like Panamax	3,500 – 4,700 TEU
CC	like Aframax	4,700 – 7,000 TEU
CC	like Suezmax	7,000 – 14,500 TEU
CC	ULCV	>14,500 TEU
Global average CC	World	over all ships
RoRo	RoRo small	< 5000 DWT
RoRo	RoRo large	>= 5000 DWT
(BC = bulk carrier; CC = container vessel; GC = general cargo ship; RoRo = Roll-on/roll-off ship; VLCC = very large crude carrier; ULCV = ultra-large container vessel)		

Table 50 – Vessel types and sizes that can be selected in the Extended input mode of ETW.

The resulting fuel consumption and emission factors are further adjusted to a default or user-specified speed reduction and cargo utilization. The following vessel types are differentiated:

- General Cargo Vessels
- Dry Bulk Carriers
- Liquid Bulk Carriers
- Container Carriers
- Roll-on-Roll-off vessels

Other vessels are not included in ETW because of their differing cargo specifications and lower relevance for the likely ETW user. Unfortunately for this study, those vessel types include LNG and LPG gas carriers as well as car carriers.

Derivation of basic fuel consumption and emission factors

The basic fuel consumption and emission factors are derived for each IMO ship type and size class, separately for main engine, auxiliary engine, and boiler, based on the methodology used in the Third IMO Greenhouse Gas Study from 2015 (see IMO 2015, p. 43 for ship types and associated parameters).

In order to account for emissions in port and return journeys, fuel consumption is modelled separately for main engine, auxiliary engine, and boiler, for a virtual one-year period in the standard assumption. The results are normalized to one tonne-kilometre (i.e. expressed in g/tkm).

The actual bottom-up emissions factors (assumed at 75% engine load) for all non-sulphur-dependent pollutants are presented in Table 32 and SO_x and PM are presented in Table 33 (see Table 22 for more details). As noted above, SO_x and PM emissions factors vary depending on the sulphur content of the fuels consumed. MEPC annual reports from the sulphur monitoring programme were used to determine the average sulphur content for both HFO and MDO/MGO fuels from 2007 to 2012. For regional variations driven by regulation (ECAs), the fuel sulphur content is assumed to be equivalent to the minimum regulatory requirement (see the description in Section 1.2 of how shipping activity is attributed to different global regions). All bottom-up emissions factors are further adjusted by engine load based on the activity data.

Emissions species	Marine HFO emissions factor (g/g fuel)	Marine MDO emissions factor (g/g fuel)	Marine LNG emissions factor (g/g fuel)
CO ₂	3.11400	3.20600	2.75000
CH ₄	0.00006	0.00006	0.05120
N ₂ O	0.00016	0.00015	0.00011
NO _x Tier 0 SSD	0.09282	0.08725	0.00783
NO _x Tier 1 SSD	0.08718	0.08195	0.00783
NO _x Tier 2 SSD	0.07846	0.07375	0.00783
NO _x Tier 0 MSD	0.06512	0.06121	0.00783
NO _x Tier 1 MSD	0.06047	0.05684	0.00783
NO _x Tier 2 MSD	0.05209	0.04896	0.00783
CO	0.00277	0.00277	0.00783
NM VOC	0.00308	0.00308	0.00301

Table 51 – Emissions factors for bottom-up emissions due to the combustion of fuels. Source: IMO third GHG study.

	% Sulphur content averages – IMO ¹					
Fuel type	2007	2008	2009	2010	2011	2012
Average Non-ECA HFO S%	2.42	2.37	2.6	2.61	2.65	2.51
SO _x EF (g/g fuel)						
Marine fuel oil (HFO)	0.04749	0.04644	0.05066	0.05119	0.05171	0.04908
Marine gas oil (MDO)	0.00264	0.00264	0.00264	0.00264	0.00264	0.00264
Natural gas (LNG)	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002
PM EF (g/g fuel)						
Marine fuel oil (HFO)	0.00684	0.00677	0.00713	0.00713	0.00721	0.00699
Marine gas oil (MDO)	0.00102	0.00102	0.00102	0.00102	0.00102	0.00102
Natural gas (LNG)	0.00018	0.00018	0.00018	0.00018	0.00018	0.00018

¹ Source: MEPC annual reports on sulphur monitoring programme

Table 52 – Year-specific bottom-up emissions factors for SO_x and PM. Source: IMO third GHG study.

It is to be noted that all emissions factors are in mass of emissions per unit mass of fuel and the specific fuel consumption data reported in the IMO's study are in units of mass of fuel, so for oil-based fuels the production of the total emissions is a straightforward multiplication. Further work is needed to compile the gas fuel emissions factors and the method for emissions calculation (the units for gas fuel use are mass of oil equivalent).

Considerations on emission control areas (ECAs)

Emissions from sea vessels are regulated in Annex VI of the “International Convention on the Prevention of Pollution from Ships”, also known as MARPOL. Annex VI defines two sets of emission and fuel quality requirements: on one hand global requirements, and on the other hand more stringent requirements applicable in so-called Emission Control Areas (ECAs). An ECA can be designated for SO_x, PM, or NO_x, or all three pollutants, subject to a proposal from a Party to Annex VI.

Existing Emission Control Areas include:

- . Baltic Sea (SO_x, adopted: 1997; entered into force: 2005)
- . North Sea (SO_x, 2005/2006)
- . North American ECA, including most of US and Canadian coast (NO_x & SO_x, 2010/2012).
- . US Caribbean ECA, including Puerto Rico and the US Virgin Islands (NO_x & SO_x, 2011/2014).

ECA-specific NO_x emission limits entered into force from 2016 but are not yet considered in ETW. Different options exist to comply with the emission limits in ECAs. Currently the most widespread is to use Marine Diesel Oil (MDO), which has a sulphur content of 0.1%. Other options are to use scrubber, an after-treatment technology that uses sea water to wash SO₂ out of the exhaust gas, or to switch to LNG instead of diesel. However, the latter two options are not very widespread: as of January 2015, only 0.6% of the world fleet was fitted with scrubbers, and even fewer ships used LNG. In ETW, it is therefore currently assumed that all ships comply with ECA emission limits (as well as special emission limits in ports) by switching to MDO. This is implemented by splitting the journey travelled into the distance within and outside ECAs. For the distance within ECAs, the fuel consumption and emission factors for MDO (Marine Diesel Oil) are applied, and for the distance outside, the factors for HFO. Besides ECAs, stricter emission limits also apply to certain ports, e.g. all ports in Europe and California. Ports in other parts of the world have voluntary fuel switch programs, which offer incentives like reduced port fees for using lower-sulphur fuels. The maximum allowed sulphur level in these programs varies. As a simplified assumption, MDO (with 0.1% sulphur content) is assumed to be used in ports with stricter emission limits or voluntary fuel switch programs, that is to say:

- All ports in Europe
- All ports in California
- Seattle, New York, New Jersey, Houston (USA)
- Vancouver (Canada)

- Hong Kong
- Singapore

The emissions of ocean-going vessels are averaged over the entire return journeys, taking the load factors and empty returns into account. All emissions are allocated to the freight carried.

For bulk vessels the allocation unit is tonne-kilometre (tkm). All emissions are allocated to the product of transported tonnes of freight and distance travelled.

[Input parameters for waterborne transport calculations](#)

As far as the parameters adopted as input for the waterborne transport calculations on the EcoTransit Tool in its extended version, as shown in figure below, a differentiation has been made between two type of vessels according to the capacity of liquid cargo (cryogenic cargo was not available among the options).

CALCULATION PARAMETERS

Weight: 990 Bulk and Unit Load (Tonnes)

t/TEU: 14.5

Define handling: -

Change

Transport service TS 1

Origin: Fos-sur-mer

Class: Liquid

Type: T Feeder (5-15k dwt) liquiud

Speed: 0.0%

LF: 100.0%

Destination: La Spezia

CALCULATION PARAMETERS

Weight: 3375 Bulk and Unit Load (Tonnes)

t/TEU: 14.5

Define handling: -

Change

Transport service TS 1

Origin: Fos-sur-mer

Class: Liquid

Type: T Handysize (15-30k dwt) liquiud

Speed: 0.0%

LF: 100.0%

Destination: La Spezia

Figure 82 – Calculation parameters used as input for EcoTransit Tool-based simulations related to LNG waterborne transport by 2.200m³ T feeder ship (left) and 7.500m³ T handysize vessel (right)

Explanation of the parameters is given as follows:

- Weight: a total load of 990 tonnes and 3375 tonnes, corresponding to about 2.200 m³ and 7.500 m³ of LNG respectively, has been envisaged reflecting the two type of unit that are most likely to be used for LNG supply;
- t/TEU: the value of 14,5 of tonnes per containerized unit is set automatically for heavy cargoes which has been selected (however, this has not any incidence on the overall calculations);
- Origin and destination: UN/LOCODE of the ports corresponding to the selected terminal of origin Terminal Ravano has been used (it is noted that for all the terminals selected, the distance between the exact port entrance/exit point and the LNG terminal themselves is rather negligible, given that LNG are located within the port's boundaries or in their close proximity);
- Class: liquid cargo type has been considered for both units;
- Type: a T Feeder vessel having a deadweight tonnage in the range of 5-15.000 tonnes has been envisaged as a credible alternative of a self-propelled barge (barges are intended for river transport only in the EcoTransit Tool's options), while a T Handysize vessel having a deadweight tonnage in the range of 15-30.000 tonnes has been envisaged as a bunkering vessel (a parameter in line with the DWT of the bunkering vessel under construction within the GAINN4MID Action as described in paragraph 2.3.5 above);
- Speed (reduction): both simulated units have been supposed sailing at full speed (therefore with a speed reduction equal to zero) as slow steaming is largely variable among companies and capable of influencing greatly energy consumption and air emissions generation);
- Loading Factor (LF):): both simulated units have been supposed to be loaded up to their maximum capacity in order to maximize efficiency.

7.3 Results of the EcoTransit-based simulations

The results of the simulations undertaken using the EcoTransit Tool for each transport mode along each defined route are reported in separate Appendices attached to the present document, as hereby recapped.

- Appendix A – EcoTransit LNG transport simulation results on single trips from existing LNG terminals.
 - A1 - Energy consumption and GHGs related to LNG road transport to supply La Spezia from existing terminals using diesel or LNG as a truck fuel.
 - A2 – Air pollutants emissions related to LNG road transport to supply La Spezia from existing terminals using diesel or LNG as a truck fuel.
 - A3 - Energy consumption and GHGs related to rail transport to supply La Spezia with LNG from existing suitable terminals.
 - A4 - Air pollutants emissions related to rail transport to supply La Spezia with LNG from existing suitable terminals.
 - A5 - Energy consumption and GHGs related to waterborne transport to supply La Spezia with LNG from existing suitable terminals via 2200 m³ or 7500 m³ feeder ships.
 - A6 – Waterborne transport 2020 scenario: GHGs and air pollutants emissions related to waterborne transport to supply La Spezia with LNG from existing suitable terminals via 2200 m³ or 7500 m³ feeder ships (LNG/conventional fuels comparison).
- Appendix B – EcoTransit LNG transport simulation results on single trips from suitable planned LNG terminals.
 - B1 - Energy consumption and GHGs related to LNG road transport to supply La Spezia from suitable planned terminals using diesel or LNG as a truck fuel.
 - B2 – Air pollutants emissions related to LNG road transport to supply La Spezia from suitable planned terminals using diesel or LNG as a truck fuel.
 - B3 - Energy consumption and GHGs related to rail transport to supply La Spezia with LNG ISO-containers from planned suitable terminals.
 - B4 - Air pollutants emissions related to rail transport to supply La Spezia with LNG ISO-containers from planned suitable terminals.
 - B5 - Energy consumption, GHGs, Air pollutants emissions related to waterborne transport to

supply La Spezia with LNG from planned suitable terminals via 2200 m³ or 7500 m³ feeder ships.

- B6 – Waterborne transport 2020 scenario. GHGs and air pollutants emissions related to waterborne transport to supply La Spezia with LNG from planned suitable terminals via 2200 m³ or 7500 m³ feeder ships (LNG/conventional fuels comparison).

7.3.1 Transport modes' respective energy consumption, GHGs and air pollutants per unit of cargo/distance

The results of the simulations focused on GHGs emissions and energy consumption associated to road transport of LNG ISO-containers along individual itinerary are presented in Appendix A1, and have been further elaborated to provide an estimation of the energy consumption and GHGs generation for unit of LNG transported for km via each suitable transport mode (and related applicable variations – e.g: diesel/LNG driven truck; 2.200 or 7.500 m³ supply vessel), as shown in the chart and related values below.

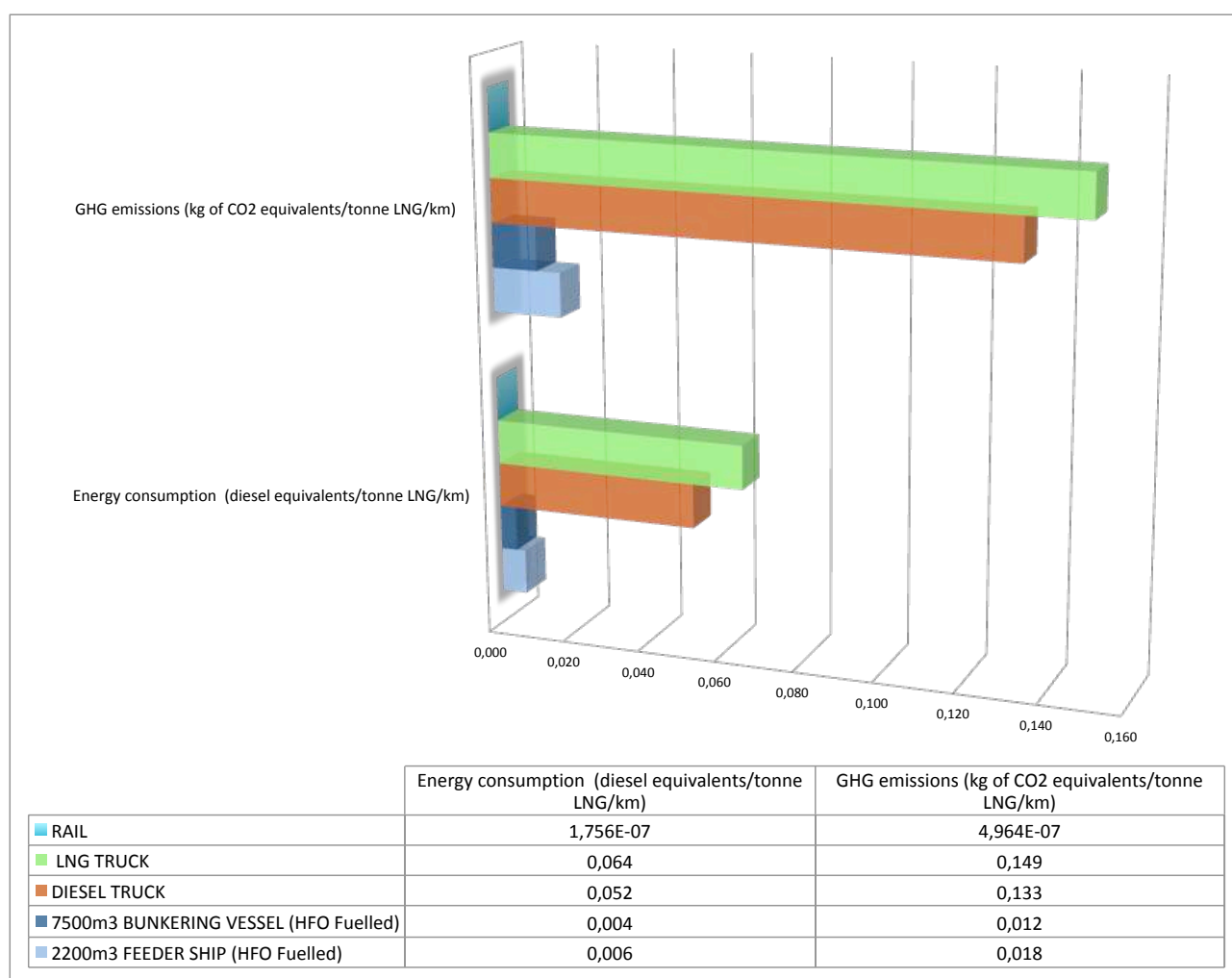


Figure 83 – Unitary energy consumption (expressed in diesel equivalents/tonne LNG/km) and GHGs (expressed as kg of CO₂ equivalents/tonne LNG/km) for the transport modes considered to supply LNG to the Port of La Spezia before 2020

Values related to rail transport are visible only in the table, given that they are off the scale compared to the road transport (no matter the fuel used by trucks) and waterborne transport. Rail transport thus results not only the less energy demanding mode of transport per tonne of LNG transported, but also the only one with a negligible contribution to the GHG emissions of transport.

GHGs emissions and energy consumption values of road transport are almost ten times greater than those related to waterborne transport, with LNG driven trucks being the less energy efficient and greater contributor to climate change.

When it comes to pollutants, the situation is somewhat different, as depicted by the figure below.

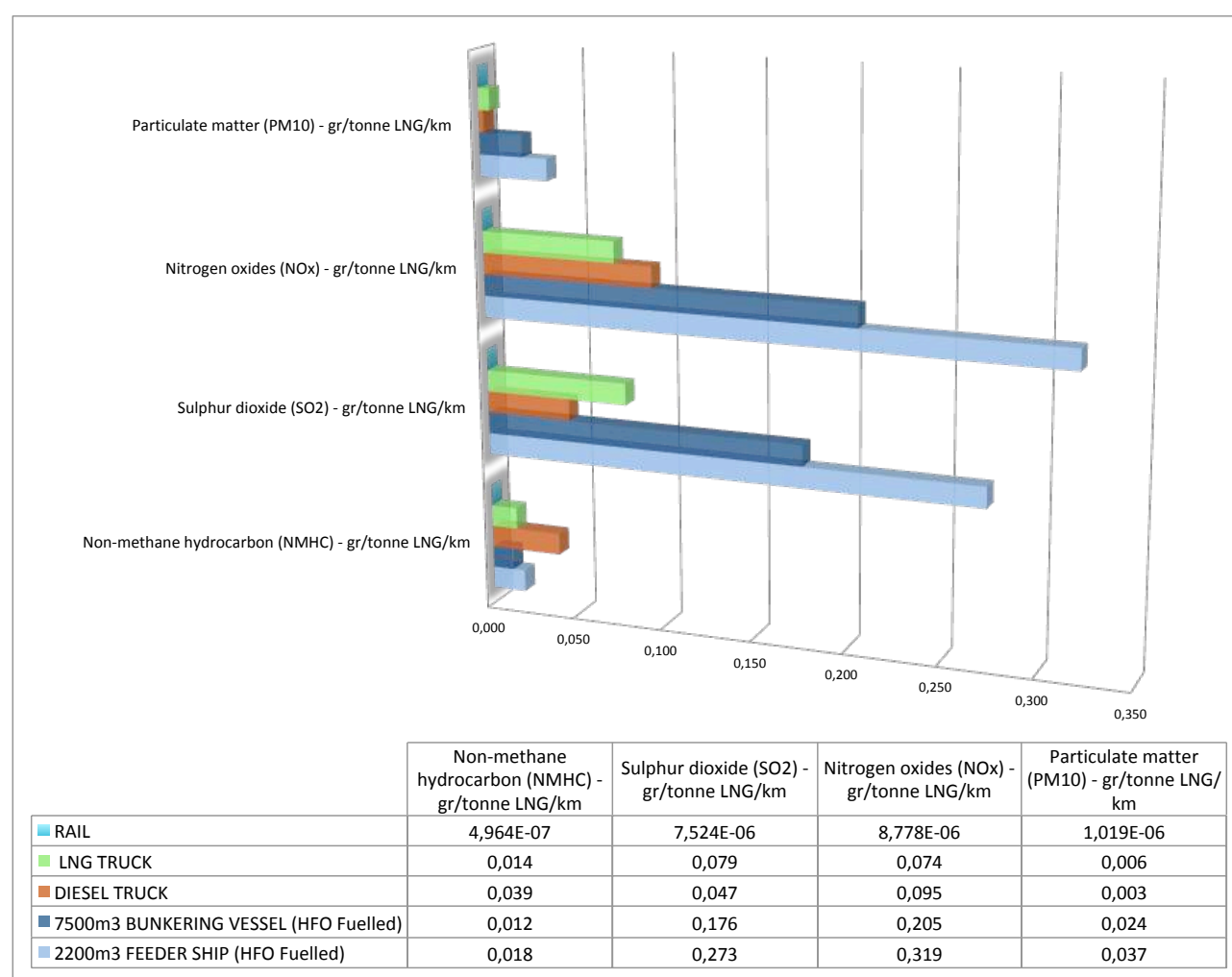


Figure 84 – Unitary air pollutants emissions (expressed in gr/tonne LNG/km) for the transport modes considered to supply LNG to the Port of La Spezia before 2020.

The first evidence is that the rail transport is again definitely off the scale on each item, being certainly the most sustainable transport mode when it comes to pollutants. Yet, the comparison between air pollutants emissions generated by road and waterborne transport is definitely different from that regarding energy

efficiency and GHGs. In fact it can be observed that exception made for NMHCs, SOx emitted by a feeder ship or a bunkering vessel are, as a mean, almost triple than those generated by road transport. The same is said for NOx emissions, while quantities of PM produced by road transport are even one order of magnitude below those generated by ship's transport.

But the situation turns again when traditional fuel for shipping is replaced by MDO or LNG. In fact, as shown in figure below, notwithstanding the best environmental performances of rail transport, the transport of LNG via relatively small feeder ship or bunkering vessel becomes more sustainable than truck transport also as far as PM and SOx emissions are concerned when MDO or LNG are used as fuel, something that from 2020 onwards will become mandatory to replace HFO and offsetting its negative repercussions on air quality. Yet, it is to be noticed that only with LNG as a fuel the waterborne transport reaches its full environmental potential, abating NOx which MDO only reduces with respect to HFO and which marks worse performance than truck transport.

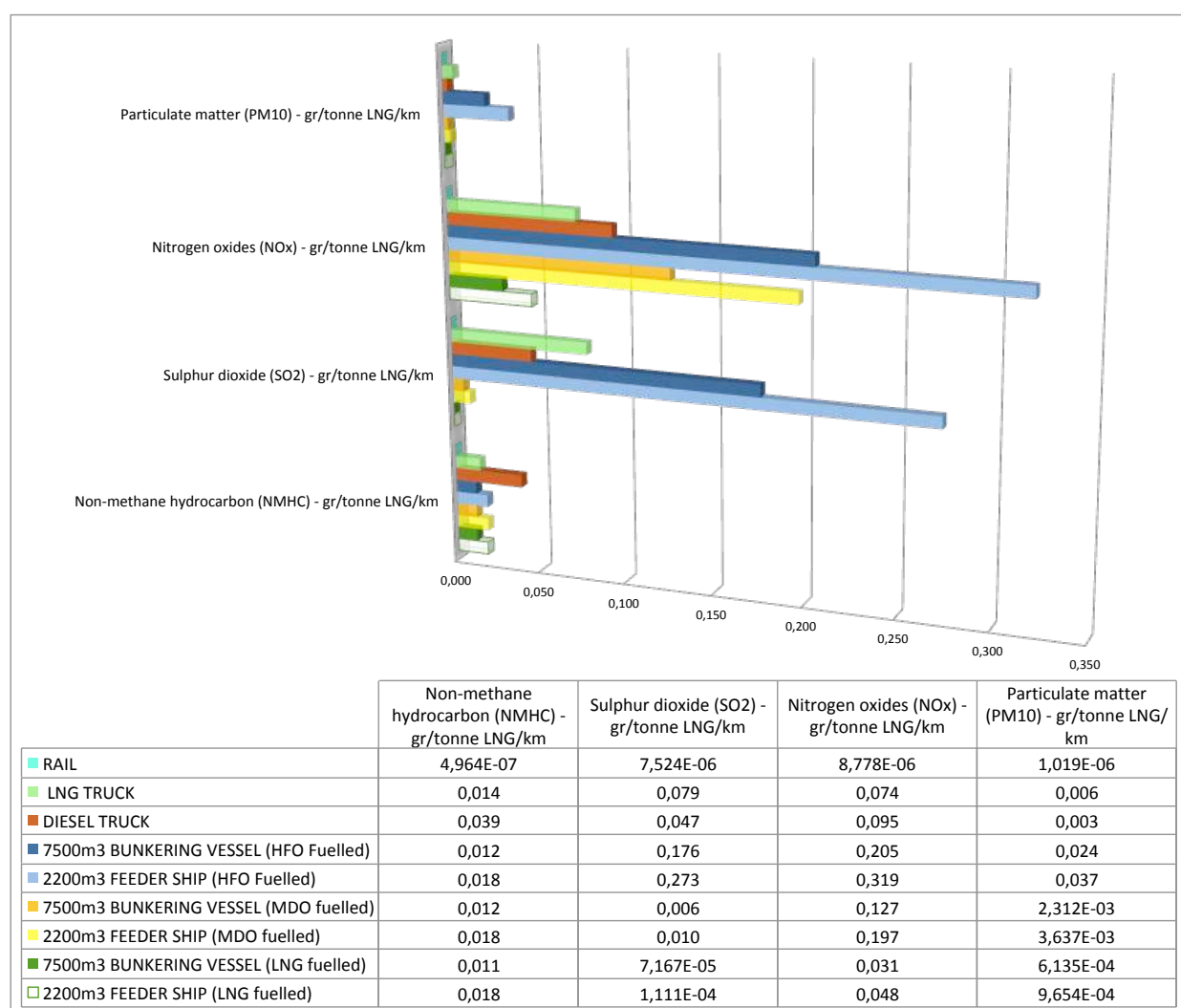


Figure 85 – Air pollutants emissions (expressed in gr/tonne LNG/km) for the transport modes considered to supply LNG to the Port of La Spezia from 2020 onwards (introducing MDO and LNG as fuels for ships).

7.3.2 Road transport's energy consumption, GHGs and air pollutants: single trips performances and elaboration with an eye towards estimations of the impacts to cover the entire LNG demand for the port of La Spezia from existing terminals

The results to follow represent the further elaboration of the outcomes of the EcoTransit Tool-based simulation presented in Appendices A1 and A2 reported at the end of this document.

Energy consumption and GHGs production

The following graph and table summarize the results differentiating between GHGs emissions (calculated as tonnes of CO₂ equivalents) and energy consumption (expressed as thousands of diesel equivalents) on single trips comparing Euro 6 diesel-driven trucks with Euro 6 LNG powered truck.

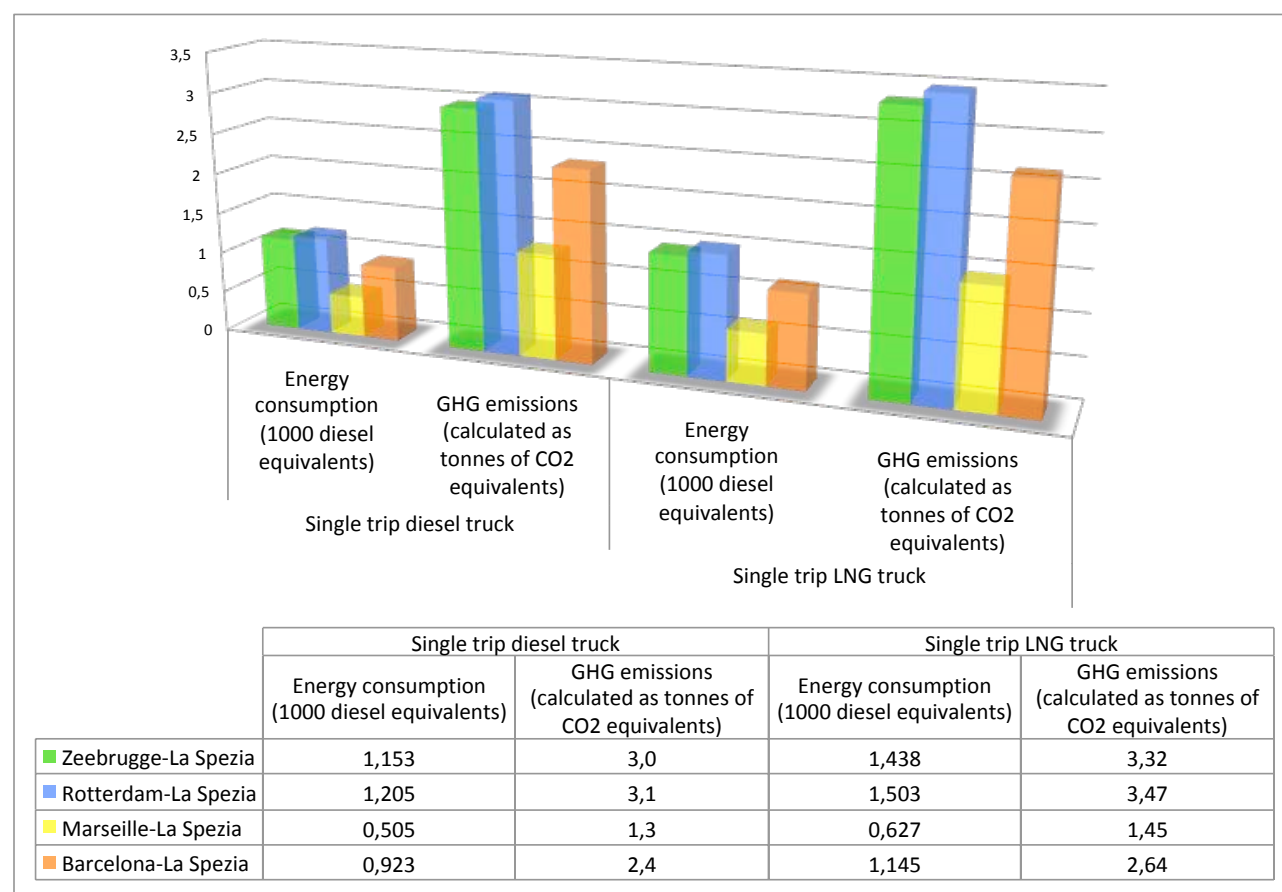


Figure 86 – Single trips energy consumption (expressed in thousands of litres of diesel equivalents) and GHGs (expressed as tonnes of CO₂ equivalents) for the supply sources considered to provide LNG to the Port of La Spezia via diesel and LNG driven trucks from existing terminals

The energy efficiency of LNG driven trucks is lower because of the fact that LNG trucks (and also CNG ones) have higher specific energy consumptions than diesel, mainly due to the lower energy efficiency of the stoichiometric spark ignition engine used for most gas trucks.

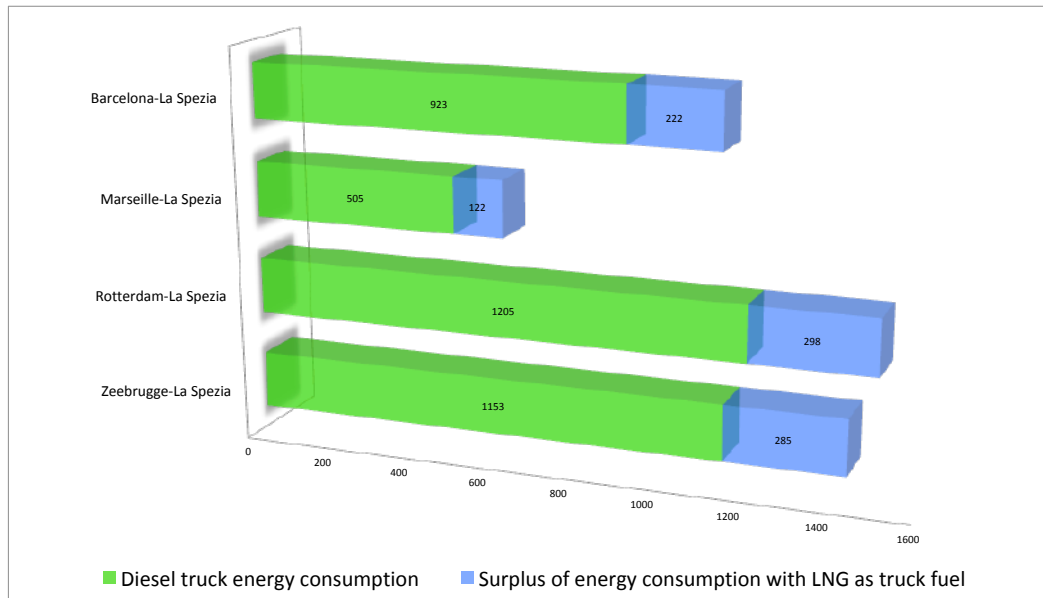


Figure 87 – Comparison of diesel/LNG driven truck transport energy performances (measured in liter of diesel equivalents) on different routes to supply LNG to La Spezia from existing terminals

Similarly, the GHGs emissions are higher for LNG drive trucks because GHGs calculations by ETW are mainly based on the energy consumption's output values.

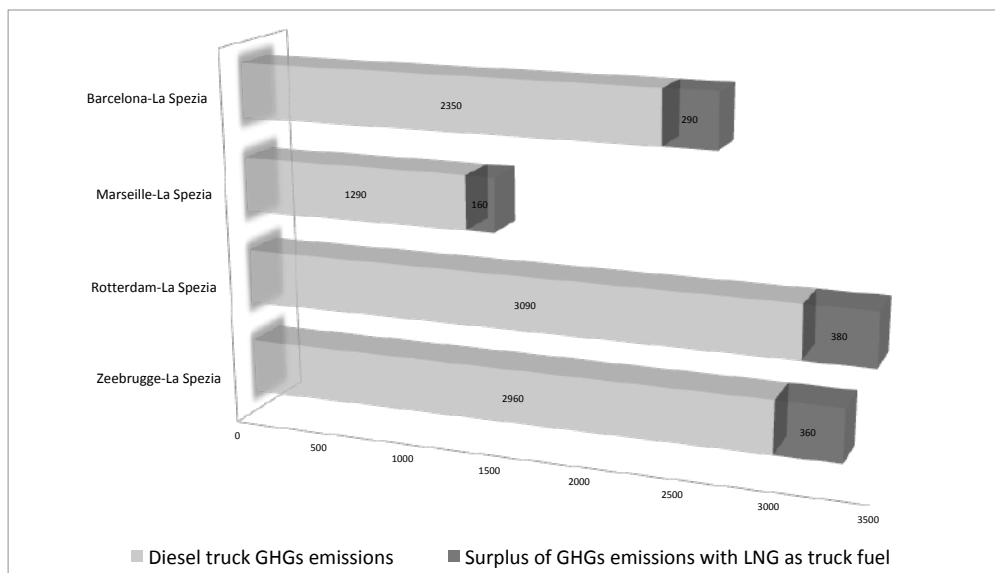


Figure 88 – Comparison of diesel/LNG driven truck transport GHGs production (expressed as kg of CO₂ equivalents) on different routes to supply LNG to La Spezia from existing terminals

Data on single trips have been elaborated in order to come up with estimations on the define pathways to supply the entire demand (higher and lower cases scenarios) of La Spezia from the existing LNG terminals. Additionally, the comparison between the emissions and energy consumption associated to the transport of LNG via a 20 or 40ft ISO-container units also resulted from the elaboration.

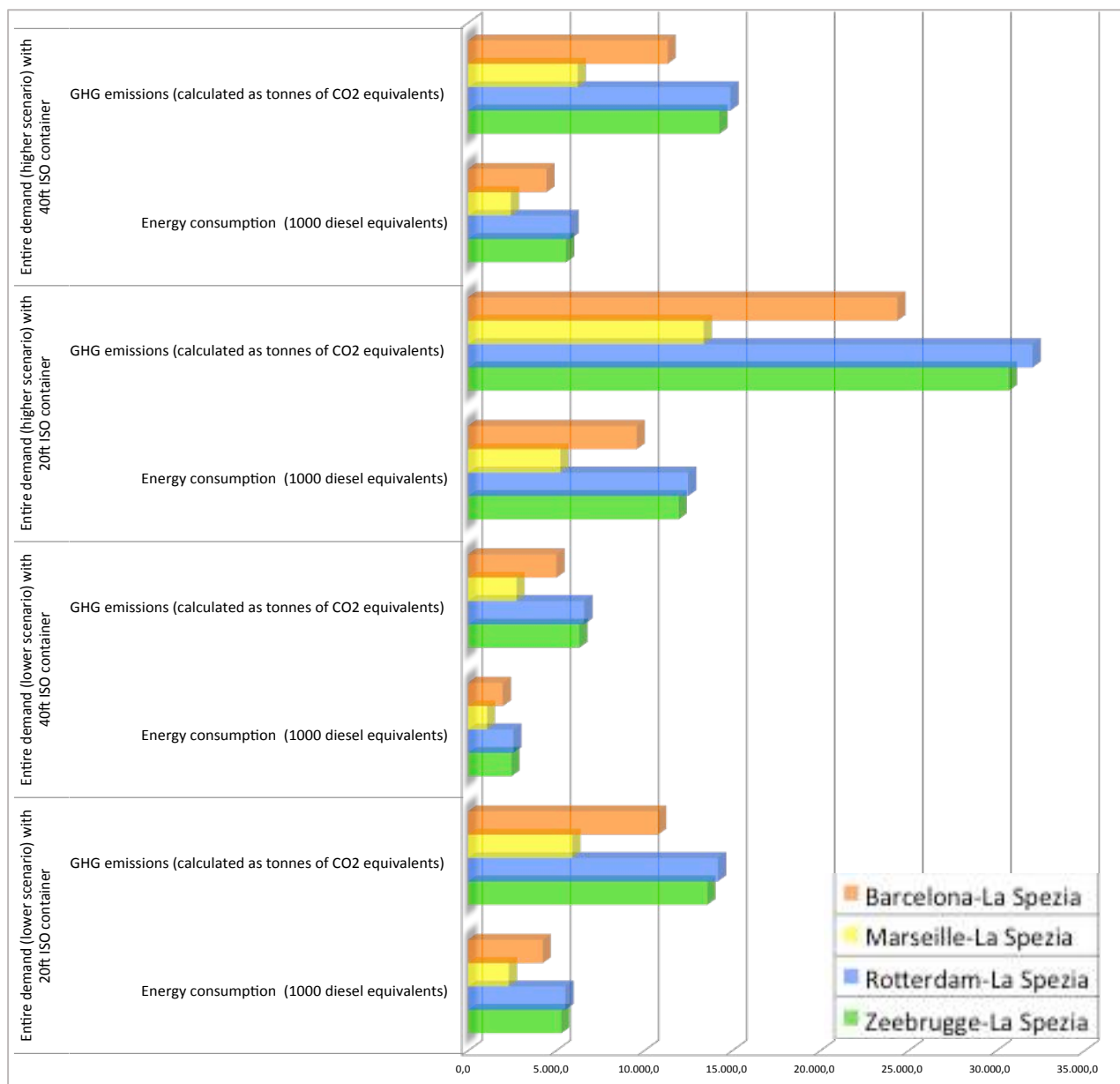


Figure 89 – LNG road transport energy consumption (shown as thousands of litres of diesel equivalents) and GHGs (shown as tonnes of CO₂ equivalents) to cover the entire LNG annual demand of the Port of La Spezia from existing terminals in the lower and higher case scenarios, via 20 and 40 ft ISO-container.

It is evident from the table below that the energy needed, and the related GHGs produced, to supply to La Spezia the amount of LNG needed to cover the future demand via road transport is rather consistent also in the lower case scenario. Using 20ft ISO container units, 4.590 trips per year will be needed (almost 89 per week), accounting for almost 6.000 tonnes of CO₂ equivalents and an energy consumption in the order of 2,3 million litres of diesel equivalents from the closest terminal of origin.

On the other side, carrying 40ft ISO container units, 2.134 truck trips per year will be needed (around 40 per week), accounting for almost 2.750 tonnes of CO₂ equivalents and an energy consumption in the order of 1 million litres of diesel equivalents from the closest terminal of origin. Values related to the higher case scenario seems to be out of scale, considering that 10.370 and 4.821 truck trips per year would be needed when carrying 20 and 40 ft ISO-container units respectively.

	Entire demand (lower scenario) with 20ft ISO container		Entire demand (lower scenario) with 40ft ISO container		Entire demand (higher scenario) with 20ft ISO container		Entire demand (higher scenario) with 40ft ISO container	
	Energy consumption (1000 diesel equivalents)	GHG emissions (calculated as tonnes of CO ₂ equivalents)	Energy consumption (1000 diesel equivalents)	GHG emissions (calculated as tonnes of CO ₂ equivalents)	Energy consumption (1000 diesel equivalents)	GHG emissions (calculated as tonnes of CO ₂ equivalents)	Energy consumption (1000 diesel equivalents)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
Barcelona-La Spezia	4.237,0	10.787,6	1.969,6	5.014,8	9.571,8	24.370,2	4.449,6	11.328,9
Marseille-La Spezia	2.318,2	5.921,7	1.077,6	2.752,8	5.237,0	13.377,7	2.434,5	6.218,8
Rotterdam-La Spezia	5.531,5	14.184,6	2.571,4	6.593,9	12.496,2	32.044,2	5.809,1	14.896,2
Zeebrugge-La Spezia	5.292,8	13.587,8	2.460,4	6.316,5	11.957,0	30.696,1	5.558,4	14.269,5

Table 53 – LNG road transport energy consumption (expressed in thousands of litres of diesel equivalents) and GHGs (expressed as tonnes of CO₂ equivalents) to cover the entire LNG annual demand of the Port of La Spezia from existing terminals in the lower and higher case scenarios, via 20 and 40 ft ISO-container transported by diesel driven truck.

As already envisageable from previous results related to the performances of Euro 6 trucks powered by diesel or LNG, the figures in terms of energy consumption and GHGs are even higher when transport via LNG trucks are foreseen, as shown in table below.

	Entire demand (lower scenario) with 20ft ISO container		Entire demand (lower scenario) with 40ft ISO container		Entire demand (higher scenario) with 20ft ISO container		Entire demand (higher scenario) with 40ft ISO container	
	Energy consumption (1000 diesel equivalents)	GHG emissions (calculated as tonnes of CO ₂ equivalents)	Energy consumption (1000 diesel equivalents)	GHG emissions (calculated as tonnes of CO ₂ equivalents)	Energy consumption (1000 diesel equivalents)	GHG emissions (calculated as tonnes of CO ₂ equivalents)	Energy consumption (1000 diesel equivalents)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
Barcelona-La Spezia	5.256,1	12.118,8	2.443,4	5.633,6	11.874,0	27.377,6	5.519,8	12.726,9
Marseille-La Spezia	2.878,2	6.656,2	1.338,0	3.094,2	6.502,2	15.036,9	3.022,6	6.990,1
Rotterdam-La Spezia	6.899,5	15.928,9	3.207,3	7.404,8	15.586,6	35.984,9	7.245,6	16.728,1
Zeebrugge-La Spezia	6.601,1	15.240,4	3.068,6	7.084,7	14.912,5	34.429,4	6.932,3	16.005,0

Table 54 – LNG road transport energy consumption (expressed in thousands of litres of diesel equivalents) and GHGs (expressed as tonnes of CO₂ equivalents) to cover the entire LNG annual demand of the Port of La Spezia from existing terminals in the lower and higher case scenarios, via 20 and 40 ft ISO-container transported by LNG driven truck.

Air pollutants emissions

With a view at contributing to represent the overall environmental impact generated on define routes to supply LNG to the Port of La Spezia, the charts and figures below provide the results of the simulations related to the air pollutants produced during road transport of LNG as a cargo from the selected terminals of origin. Given the unsuitability of 20ft ISO containers, by virtue of their limited LNG capacity that would require an unsustainable number of trips to cover the entire demand by trucks able to carry only one unit at a time, the elaboration of the results of sing trips has been restricted to a situation that envisages only the use of 40 ft units.

In the lower case scenario, LNG transport from Marseille, being the closest source of supply for La Spezia, the environmental impact would be rather consistent. Distribution of pollutants for each route and each truck powering technology is here below provided.

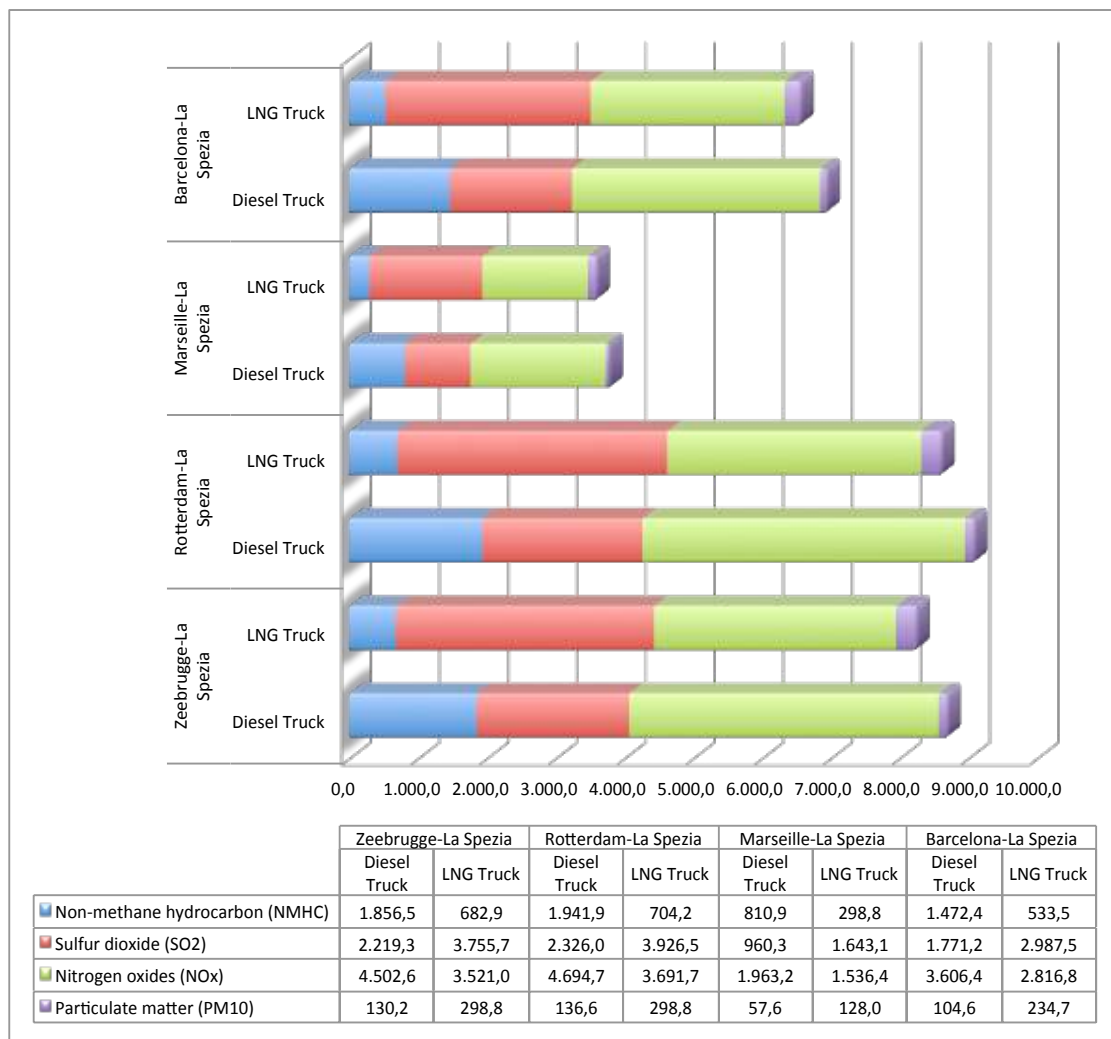


Figure 90 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG road transport to supply LNG to La Spezia from existing terminals via both diesel and LNG driven truck (carrying 40 ft ISO-container unit), to cover the entire demand in the lower case scenario.

Predictably, air pollutants emissions deriving from the LNG supply via road transport in the higher case scenario from existing terminals are more than doubled.

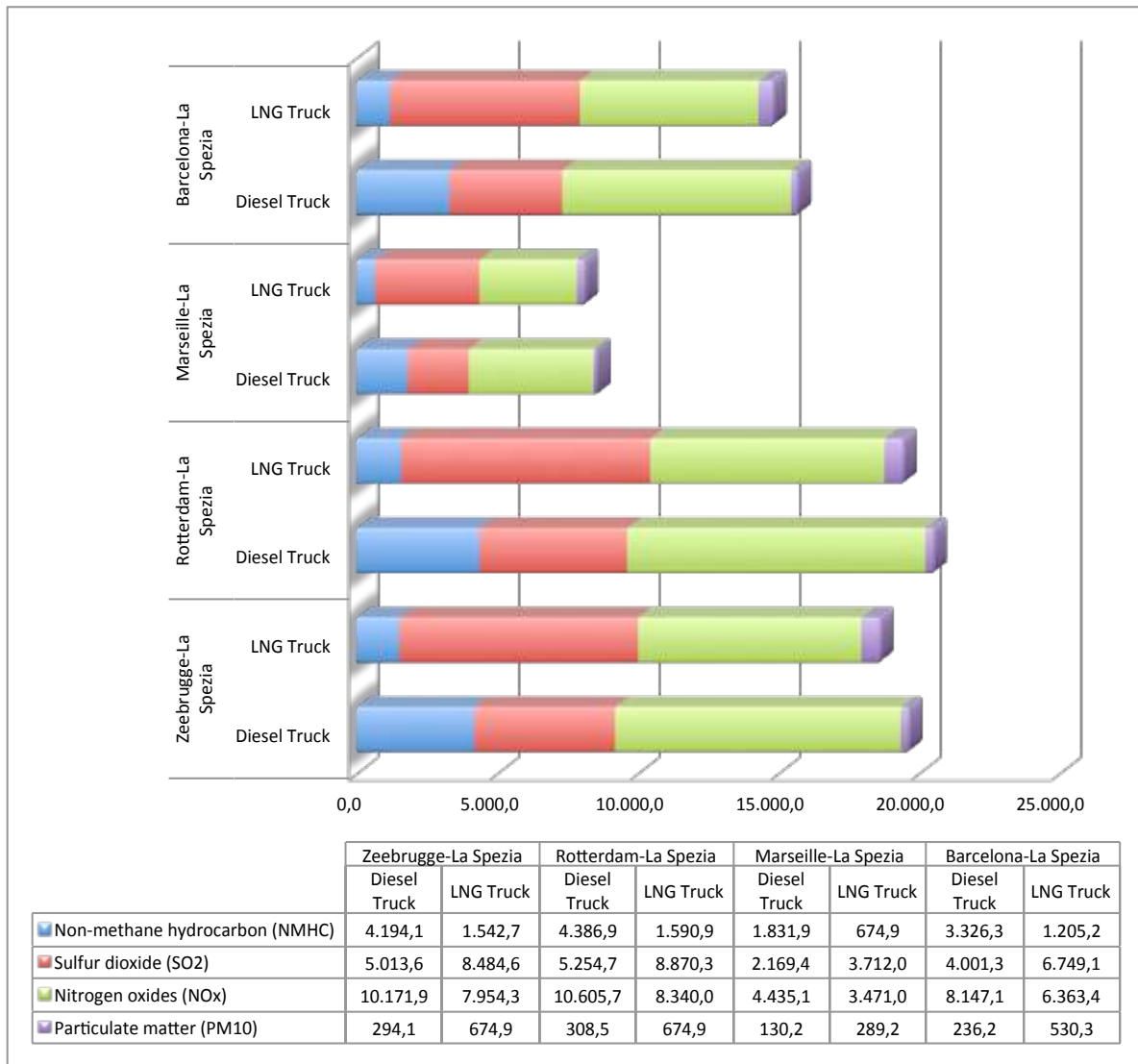


Figure 91 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG road transport to supply LNG to La Spezia from existing terminals via both diesel and LNG driven truck (carrying 40 ft ISO-container unit), to cover the entire demand in the higher case scenario.

7.3.3 Road transport's energy consumption, GHGs and air pollutants: single trips performances and elaboration with an eye towards estimations of the impacts to cover the entire LNG demand for the port of La Spezia from suitable planned terminals

The results to follow represent the further elaboration of the outcomes of the EcoTransit Tool-based simulation presented in Appendices B1 and B2 reported at the end of this document.

Energy consumption and GHGs production

With a view at allowing the comparison with the outcomes of the simulation encompassing existing LNG terminals to supply La Spezia, the same elaborations have been made depicting a scenario in which the LNG supply would come from suitable planned terminals.

Therefore, the following graph and table summarize the results related to road transport supply from the planned terminals located in Livorno and Venezia (see main technical features at paragraph 2.3.5 and 2.3.6 respectively) differentiating between GHGs emissions (calculated as tonnes of CO₂ equivalents) and energy consumption (expressed as thousands of diesel equivalents) on single trips comparing Euro 6 diesel-driven trucks with Euro 6 LNG driven truck.

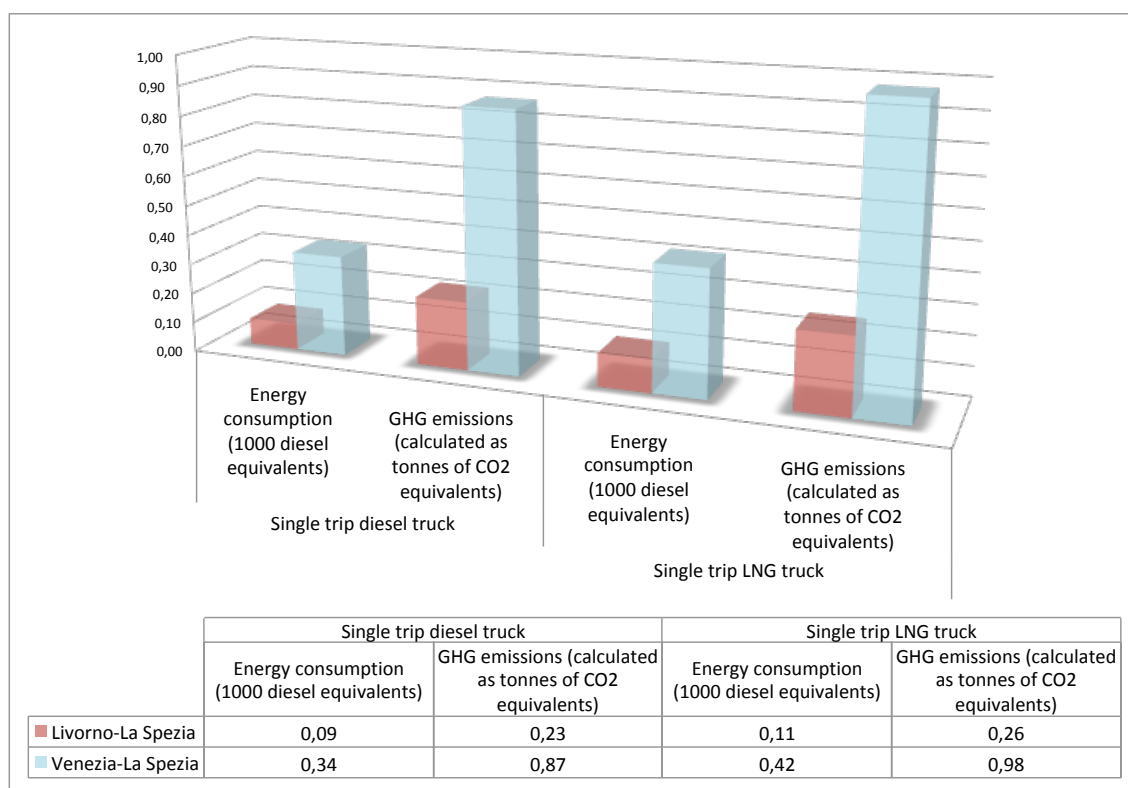


Figure 92 – Single trips energy consumption (expressed in thousands of litres of diesel equivalents) and GHGs (expressed as tonnes of CO₂ equivalents) for the supply sources considered to provide LNG to the Port of La Spezia via diesel and LNG driven trucks from suitable planned terminals

Likewise for existing terminals, data on single trips have been elaborated in order to come up, here below, with estimations related to the LNG supply to cover the entire future demand (higher and lower cases scenarios) of La Spezia from Livorno and Venezia forthcoming facilities. Additionally, the comparison between the emissions and energy consumption associated to the transport of LNG via a 20 or 40ft ISO-container units has been also undertaken.

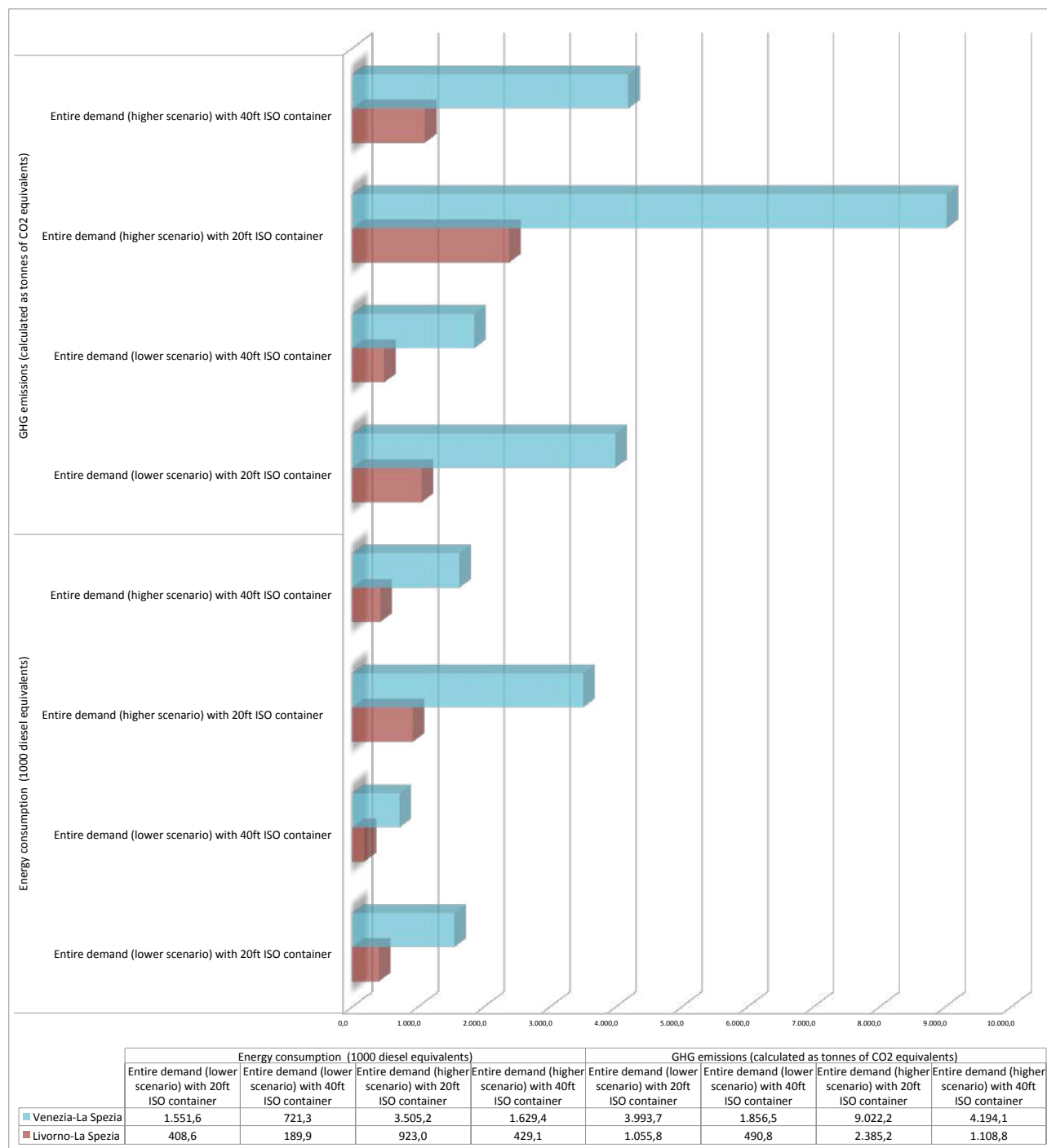


Figure 93 – LNG road transport energy consumption (expressed as thousands of litres of diesel equivalents) and GHGs (expressed as tonnes of CO₂ equivalents) to cover the entire LNG annual demand of the Port of La Spezia from suitable planned terminals in the lower and higher case scenarios, via 20 and 40 ft ISO-container.

Air pollutants emissions

The charts and figures below provide the results of the simulations related to the air pollutants produced during road transport of LNG as a cargo from the planned terminals in Livorno and Venezia. Given the unsuitability of 20ft ISO containers, by virtue of their limited LNG capacity that would require an unsustainable number of trips to cover the entire demand by trucks able to carry only one unit at a time, also in this case the elaboration of the results of sing trips has been restricted to a situation that envisages only the use of 40 ft units.

The environmental impact associated to the supply from Livorno is still consistent but remains in a reasonable range as far as the lower case scenario is concerned, being almost 75% lower than that associated to the supply from Venezia (being in turn one third less impacting than the supply from Marseille).

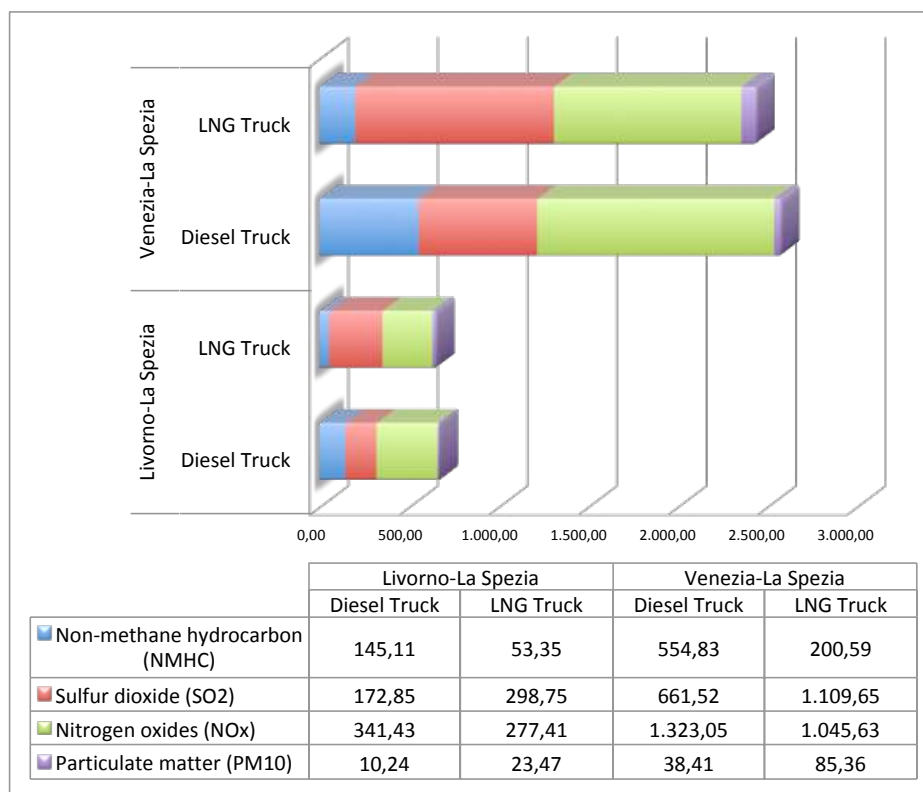


Figure 94 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG road transport to supply LNG to La Spezia from suitable planned terminals via both diesel and LNG driven truck (carrying 40 ft ISO-container unit), to cover the entire demand in the lower case scenario.

Also air pollutants emissions deriving from the LNG supply via road transport in the higher case scenario from planned terminals are more than doubled with respect to those associated to the lower case scenario.

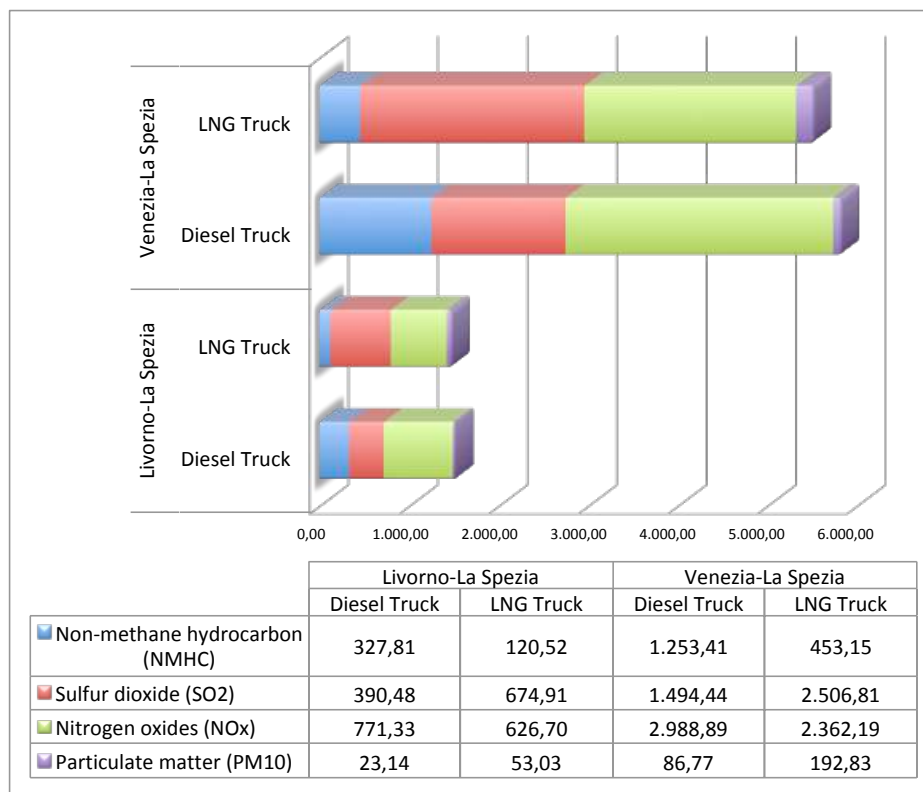


Figure 95 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG road transport to supply LNG to La Spezia from suitable planned terminals via both diesel and LNG driven truck (carrying 40 ft ISO-container unit), to cover the entire demand in the higher case scenario.

7.3.4 Railway transport's energy consumption, GHGs and air pollutants: single trips performances and elaboration with an eye towards estimations of the impacts to cover the entire LNG demand for the port of La Spezia from existing terminals

The results to follow represent the further elaboration of the outcomes of the EcoTransit Tool-based simulation presented in Appendices A3 and A4 reported at the end of this document.

Energy consumption and GHGs production

Data on single trips have been elaborated in order to come up with estimations on the define pathways to supply the entire demand (higher and lower cases scenarios) of La Spezia from the existing LNG terminals via rail transport. Additionally, the comparison between the emissions and energy consumption associated to the transport of LNG via a 20 or 40ft ISO-container units also resulted from the elaboration.

Values differs greatly from those associated to road transport, not only by virtue of the unsurprisingly better performance of rail, but also and most noticeably because this transport mode allows for the transport of a grater number of ISO-container units at a time. Results shown hereinafter are in fact referred to simulations encompassing the transport of 10 ISO-container units on each single trip, meaning around 9 and 4 trips per week if 20 ft or 40 ft units respectively are considered to cover the entire yearly demand of the Port of La Spezia in the lower case scenario, and around 20 and 9 trips per week if 20 ft or 40 ft units respectively are considered.

It is remarkable that the energy consumption and GHGs emissions associated to the transport of all the LNG by rail in the higher case scenario from the farthest source of supply is half than those associated to truck transport from the closest (and still not existing, thus potential) source of supply, namely Livorno.

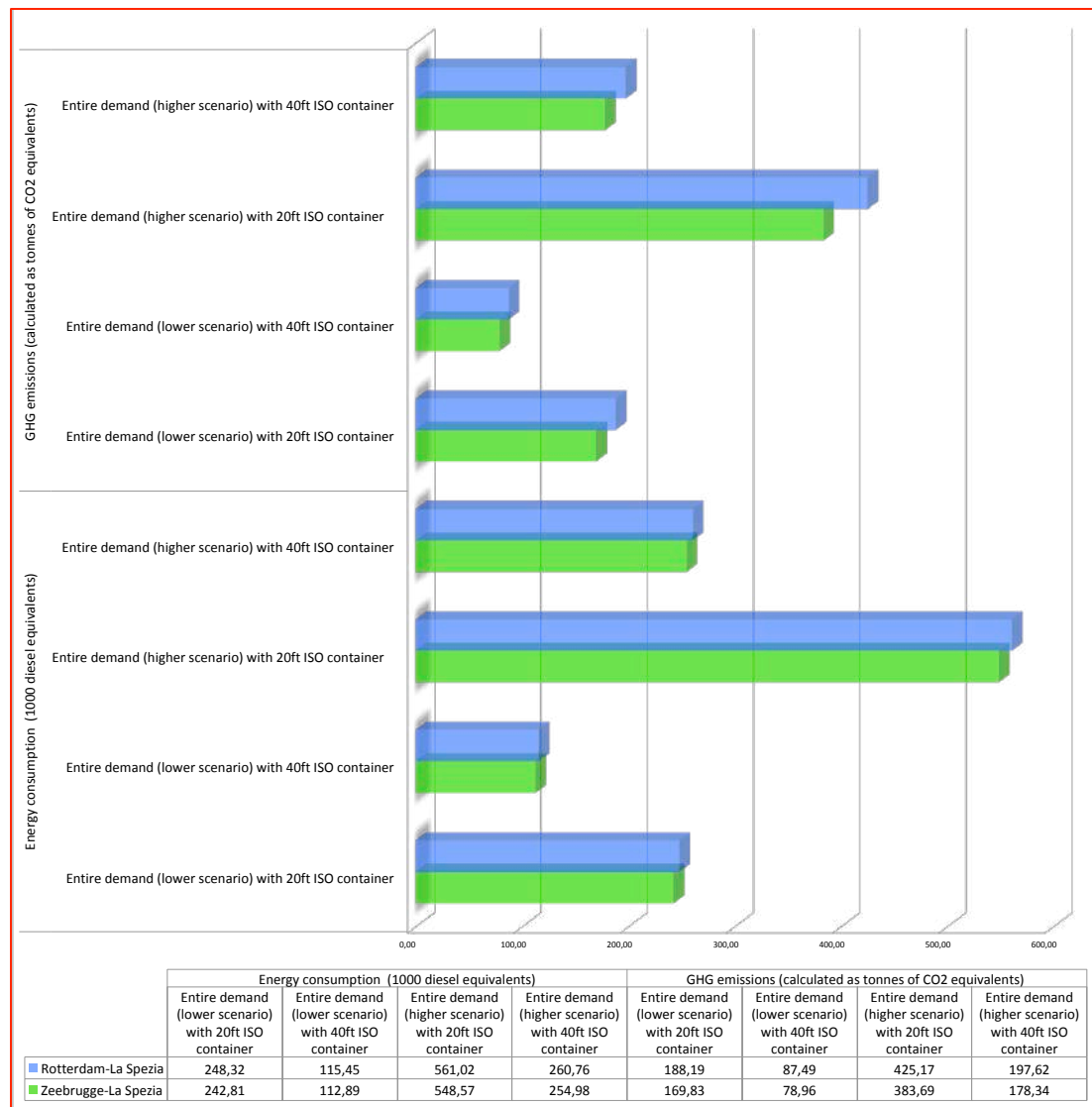


Figure 96 – LNG rail transport energy consumption (expressed as thousands of litres of diesel equivalents) and GHGs (expressed as tonnes of CO₂ equivalents) to cover the entire LNG annual demand of the Port of La Spezia from existing terminals assuming to carrying 10 units of 20ft and 40 ft ISO-container on each trip in the lower and higher case scenarios.

Air pollutants emissions

The charts and figures below provide the results of the simulations related to the air pollutants produced by rail transport of LNG as a cargo from the suitable existing terminals, in this case measurable on the scale of kilograms (unlikely those related to road transport which were one order of magnitude higher).

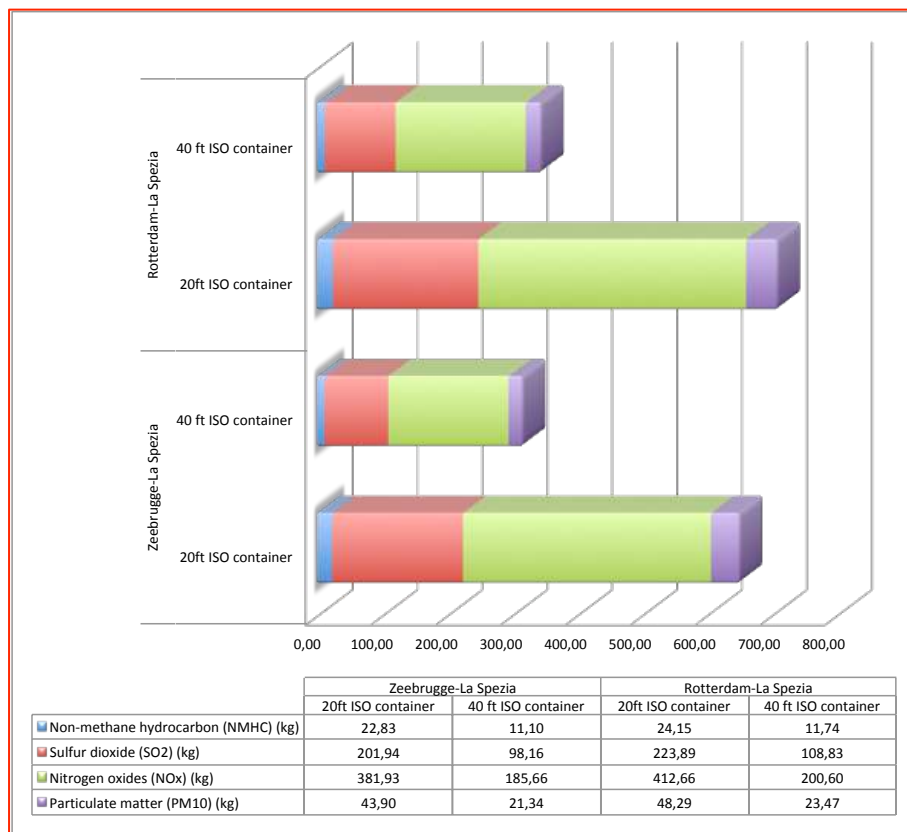


Figure 97 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG rail transport to supply LNG to La Spezia from existing terminals assuming to carrying 10 units of 20ft and 40 ft ISO-container on each trip, to cover the entire demand in the lower case scenario.

Values associated to the higher case scenario are almost doubled but still quite reasonable.

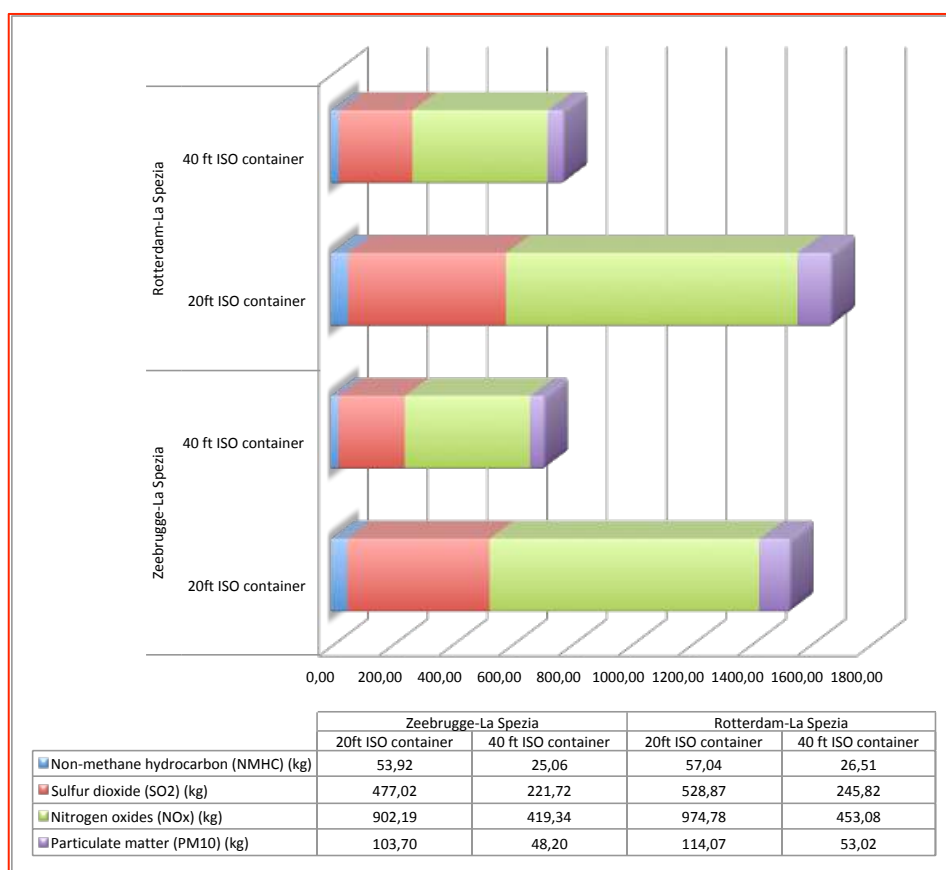


Figure 98 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG rail transport to supply LNG to La Spezia from existing terminals assuming to carrying 10 units of 20ft and 40 ft ISO-container on each trip, to cover the entire demand in the higher case scenario.

7.3.5 Railway transport's energy consumption, GHGs and air pollutants: single trips performances and elaboration with an eye towards estimations of the impacts to cover the entire LNG demand for the port of La Spezia from suitable planned terminals

The results to follow represent the further elaboration of the outcomes of the EcoTransit Tool-based simulation presented in Appendices B3 and B4 reported at the end of this document.

Energy consumption and GHGs production

With a view at allowing the comparison with the outcomes of the simulation encompassing existing LNG terminals to supply La Spezia, the same elaborations have been made depicting a scenario in which the LNG supply would come from suitable planned terminals.

Therefore, the following graph and table summarize the results related to rail transport supply from the planned terminals located in Livorno and Venezia (see main technical features at paragraph 2.3.5 and 2.3.6

respectively) differentiating between GHGs emissions (calculated as tonnes of CO₂ equivalents) and energy consumption (expressed as thousands of diesel equivalents), envisaging the simultaneous transport of 10 containerized loads on each trip.

As can be seen, the ratio between energy consumption and GHGs is different from what previously observed as the well-to-tank emissions are not the same everywhere.

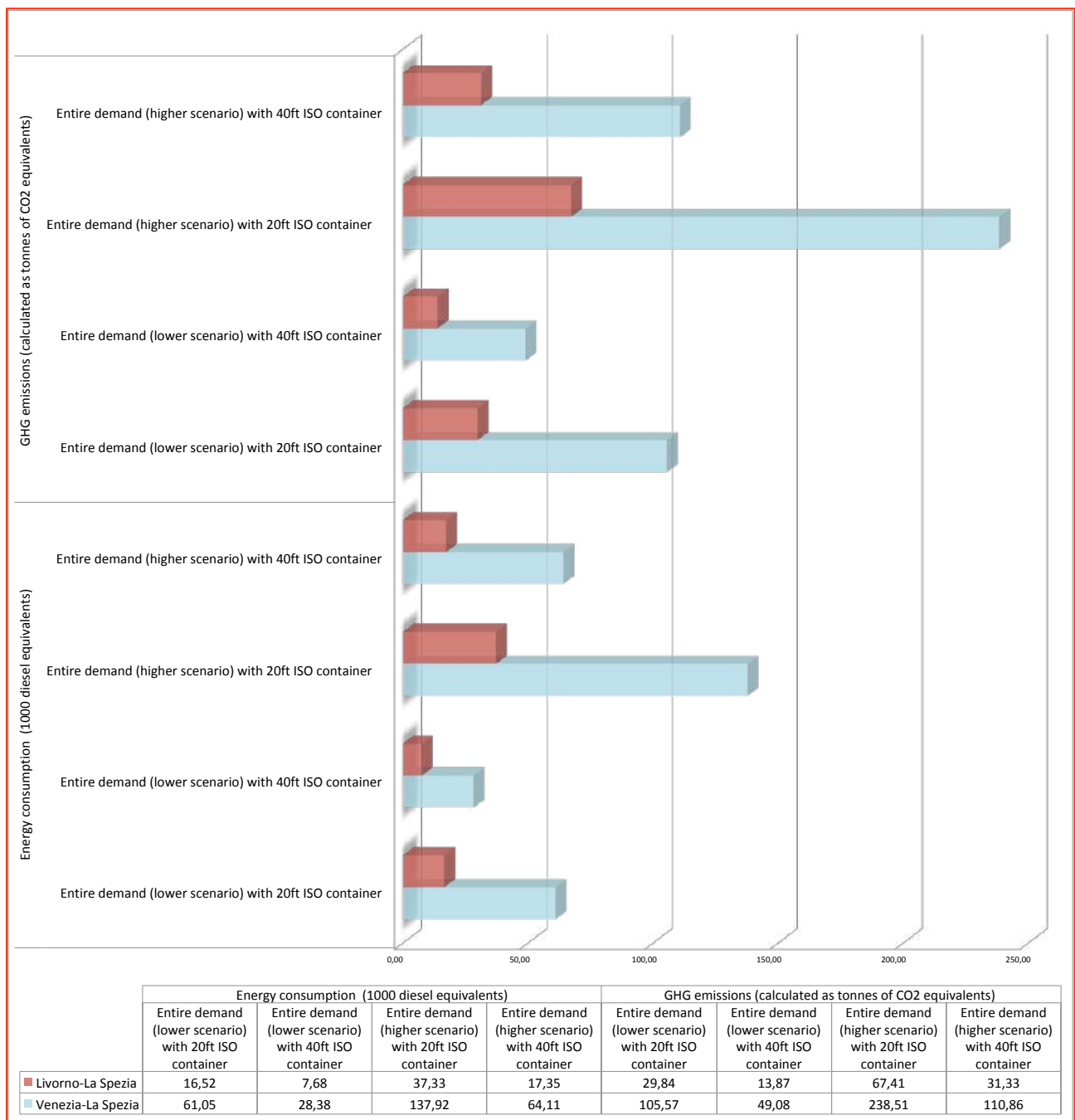


Figure 99 – LNG rail transport energy consumption (expressed as thousands of litres of diesel equivalents) and GHGs (expressed as tonnes of CO₂ equivalents) to cover the entire LNG annual demand of the Port of La Spezia from suitable planned terminals in the lower and higher case scenarios, via 20 and 40 ft ISO-container.

Also in this case, around 9 and 4 trips per week if 20 ft or 40 ft units respectively were envisaged to cover the entire yearly demand of the Port of La Spezia in the lower case scenario, against around 20 and 9 trips per week if 20 ft or 40 ft units respectively are considered.

Air pollutants emissions

The charts and figures below provide the results of the simulations related to the air pollutants produced during rail transport of LNG as a cargo from the suitable planned terminals.

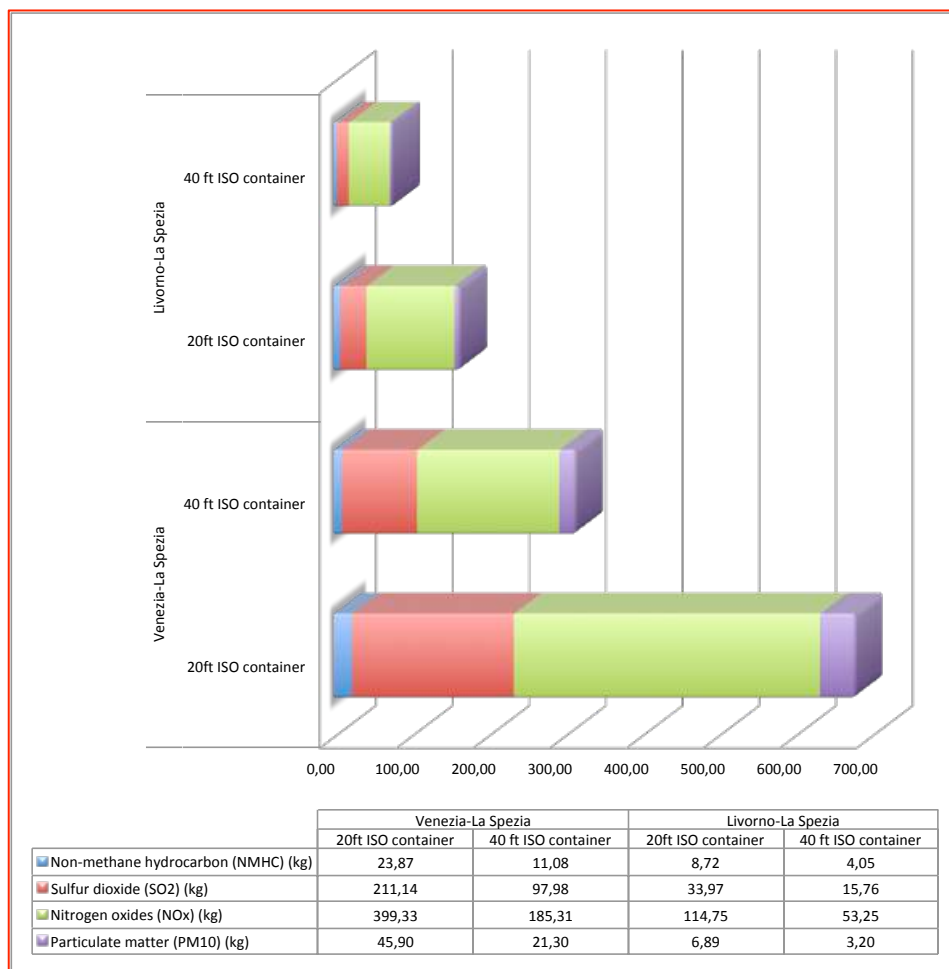


Figure 100 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG rail transport to supply LNG to La Spezia from suitable planned terminals assuming to carrying 10 units of 20ft and 40 ft ISO-container on each trip, to cover the entire demand in the lower case scenario.

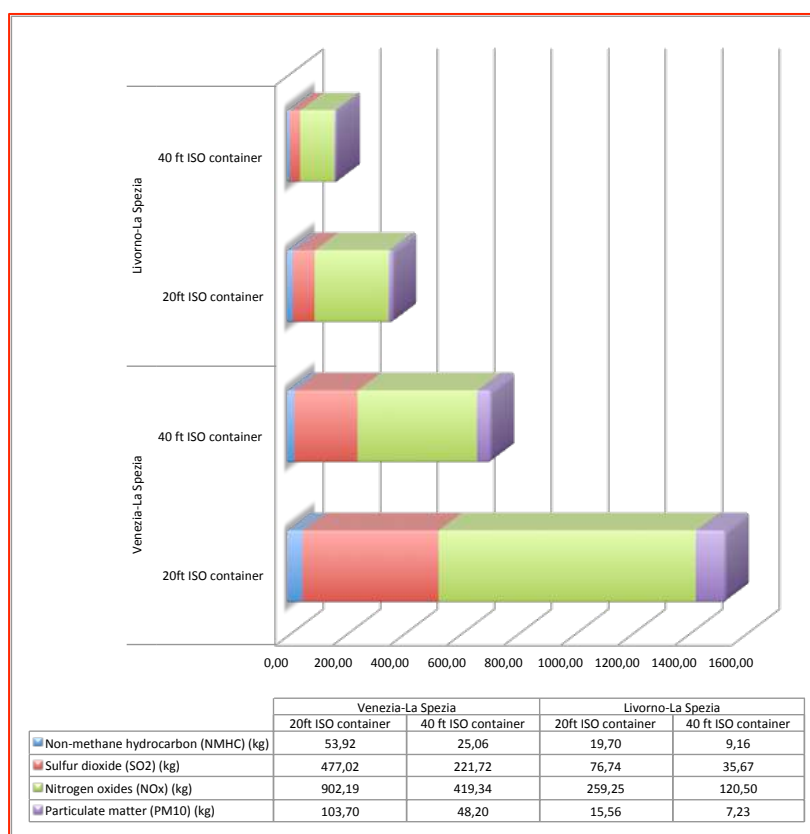


Figure 101 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG rail transport to supply LNG to La Spezia from suitable planned terminals assuming to carrying 10 units of 20ft and 40 ft ISO-container on each trip, to cover the entire demand in the lower case scenario.

7.3.6 Waterborne transport's energy consumption, GHGs and air pollutants: single trips performances and elaboration with an eye towards estimations of the impacts to cover the entire LNG demand for the port of La Spezia from existing terminals

The results to follow represent the further elaboration of the outcomes of the EcoTransit Tool-based simulation presented in Appendices A5 and A6 reported at the end of this document.

Energy consumption and GHGs production

As a first step, the data on single trips have been elaborated in order to come up with estimations to supply the entire demand (higher and lower cases scenarios) of La Spezia from the existing LNG terminals by ship. Additionally, the comparison between the emissions and energy consumption associated to the transport of LNG via 2.200 and 7.500 m3 feeder ships (traditionally fuelled and loaded at full capacity) also resulted from the elaboration.

In the lower case scenario, the best performance in terms of energy consumption and GHG production would come from a supply service based on 12 trips of a 7.500 m3 bunkering vessel providing LNG from Marseille. Using such a service as unique supply modality, around 220 tonnes of CO2 equivalents would be generated in the front of an energy consumption of around 78.000 litres of diesel equivalent throughout the year to meet demand requirements in a 2025 perspective.

Should the higher case scenario be considered, then around 27 trips would be necessary, thus GHGs production would rise up to around 500 tonnes of CO₂ equivalents, in the front of 177.000 litres of diesel equivalent produced on a yearly basis. On the contrary, it would be far less energy efficient and more contributing to climate change the use of a 2.200 m3 feeder ship, which not only has worst performance on a single trip basis, but would need almost three times the trips to cover the future demand, namely 40 and 90 trips for the lower and higher case scenarios respectively.

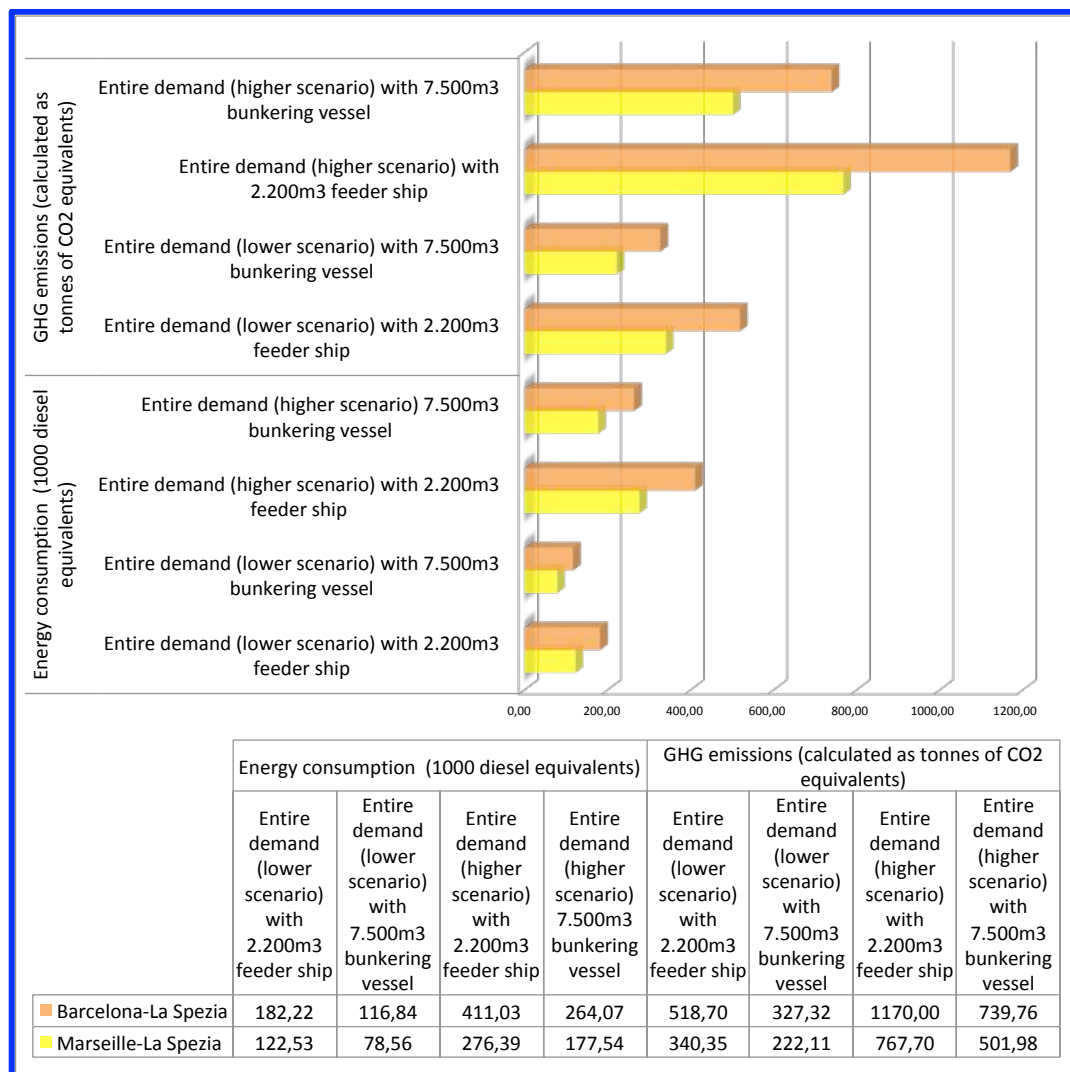


Figure 102 – LNG waterborne transport energy consumption (expressed as thousands of litres of diesel equivalents) and GHGs (expressed as tonnes of CO₂ equivalents) to cover the entire LNG annual demand of the Port of La Spezia from existing terminals in the lower and higher case scenarios, via 2.200 and 7.500 m³ feeder ships (traditionally fuelled) loaded at full capacity.

Given that in 2025 (horizon for the LNG demand estimation) the global sulphur cap will be a consolidated reality, a simulation on the GHGs produced by the same supply services if they were performed using MDO or LNG as fuel has been undertaken, resulting in the charts and values reported hereinafter, differentiating between the lower and higher case LNG demand scenarios for the Port of La Spezia.

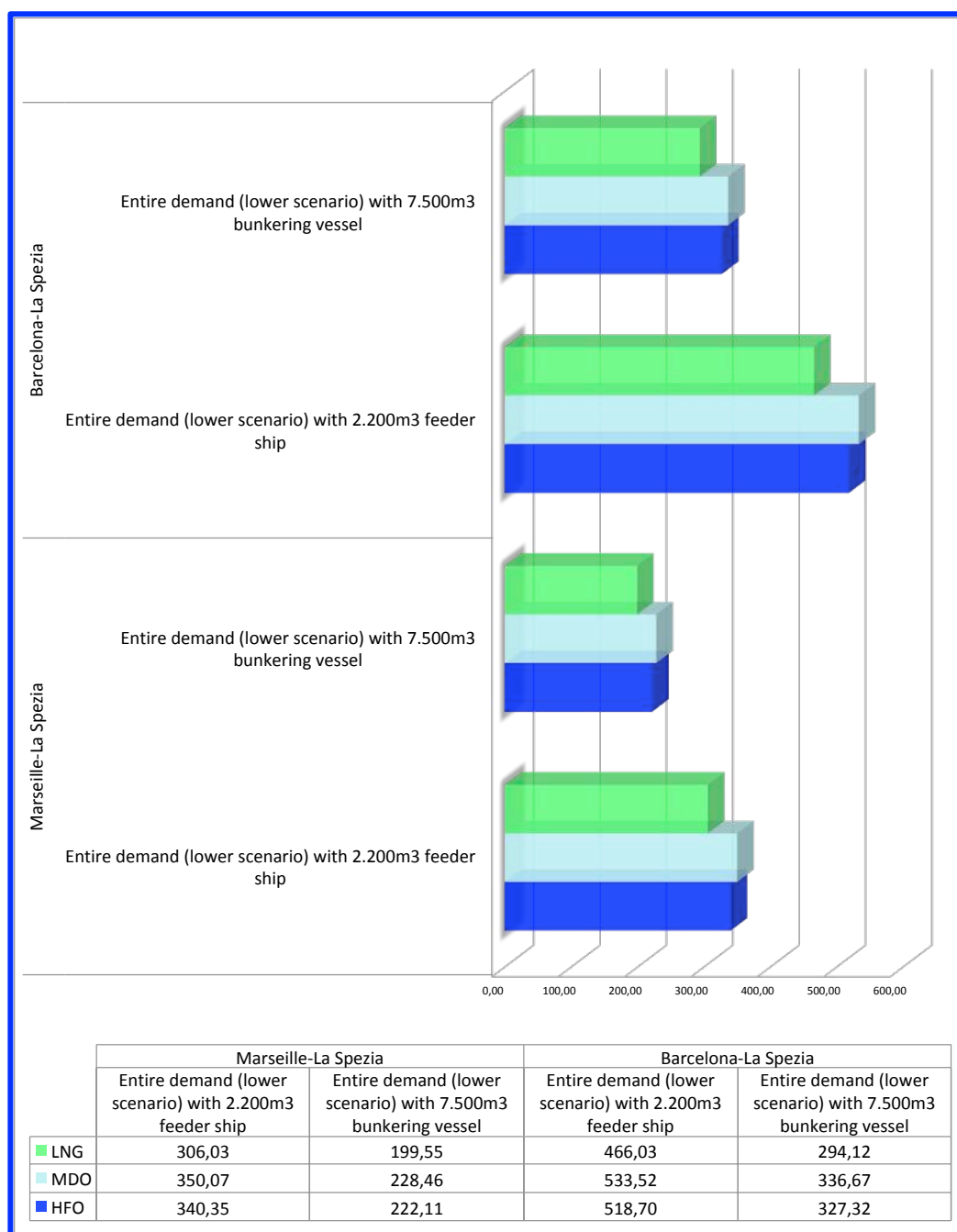


Figure 103 – Comparison of maritime fuels performances: GHGs (expressed as tonnes of CO₂ equivalents) to cover the entire LNG annual demand of the Port of La Spezia from existing terminals in the lower case scenario, via 2.200 and 7.500 m³ feeder ships loaded at full capacity and fuelled by traditional fuel (mainly HFO), MDO and LNG.

Noticeably, the GHGs produced by LNG driven supply vessels are only slightly less compared to MDO powered ones, which marked a stronger contribution to climate change than traditional fuel.

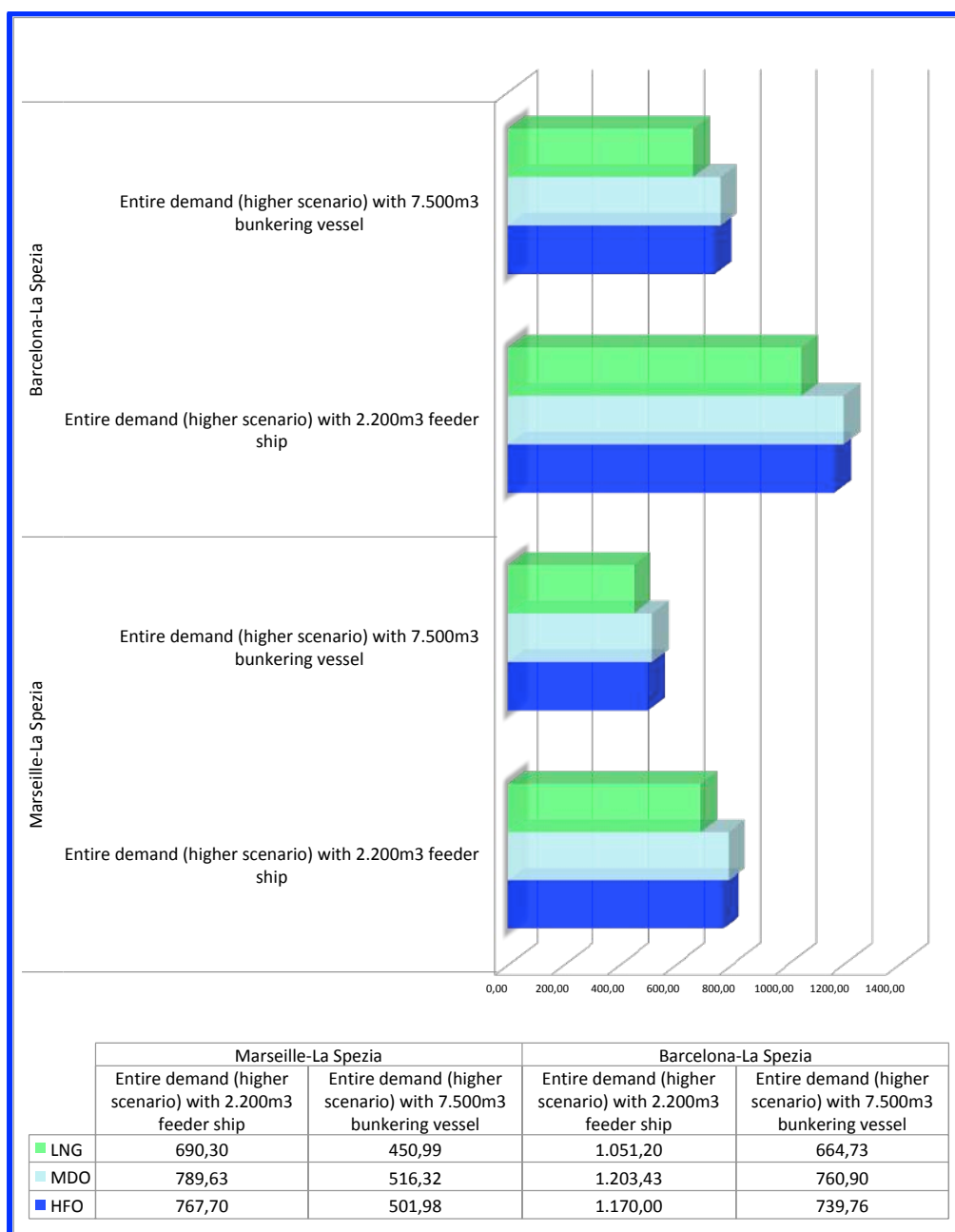


Figure 104 – Comparison of maritime fuels performances: GHGs (expressed as tonnes of CO₂ equivalents) to cover the entire LNG annual demand of the Port of La Spezia from existing terminals in the higher case scenario, via 2.200 and 7.500 m³ feeder ships loaded at full capacity and fuelled by traditional fuel (mainly HFO), MDO and LNG.

Air pollutants emissions

The charts and figures below provide the results of the simulations related to the air pollutants produced by maritime transport of LNG as a cargo from the suitable existing terminals.

The differentiation among the environmental performances of ships powered by traditional HFO fuel (deep blue framed), MDO (light blue framed) and LNG (light green framed), allows to appreciate the different distribution of pollutants for each fuel type.

The first three boxes are related to the lower case LNG demand scenario, while the others to follow to the higher case one.

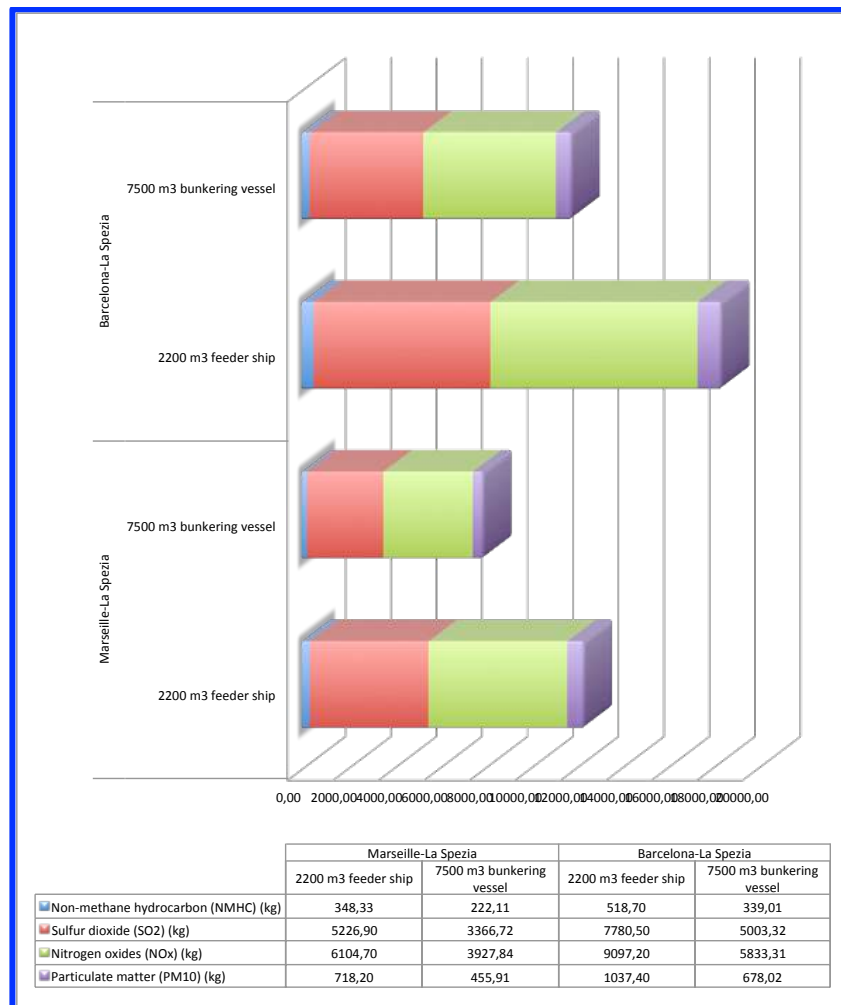


Figure 105 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG waterborne transport to supply LNG to La Spezia from existing terminals via 2.200 and 7.500 m³ feeder ships (traditionally fuelled) loaded at full capacity on each trip, to cover the entire demand in the lower case scenario.

In the lower case scenario, the best performance in terms of NMHC production would come from a supply service based on 12 trips of a 7.500 m3, LNG fuelled bunkering vessel providing LNG from Marseille. Using such a service as unique supply modality, around 2017 kg of NMHC would be generated in the front of an energy consumption of around 78.000 litres of diesel equivalent throughout the year to meet demand requirements in a 2025 perspective.

Should the higher case scenario be considered, then around 27 trips would be necessary, thus GHGs production would rise up to around 500 tonnes of CO₂ equivalents, in the front of 177.000 litres of diesel equivalent produced on a yearly basis. On the contrary, it would be far less energy efficient and more contributing to climate change the use of a 2.200 m3 feeder ship, which not only has worst performance on a single trip basis, but would need almost three times the trips to cover the future demand, namely 40 and 90 trips for the lower and higher case scenarios respectively.

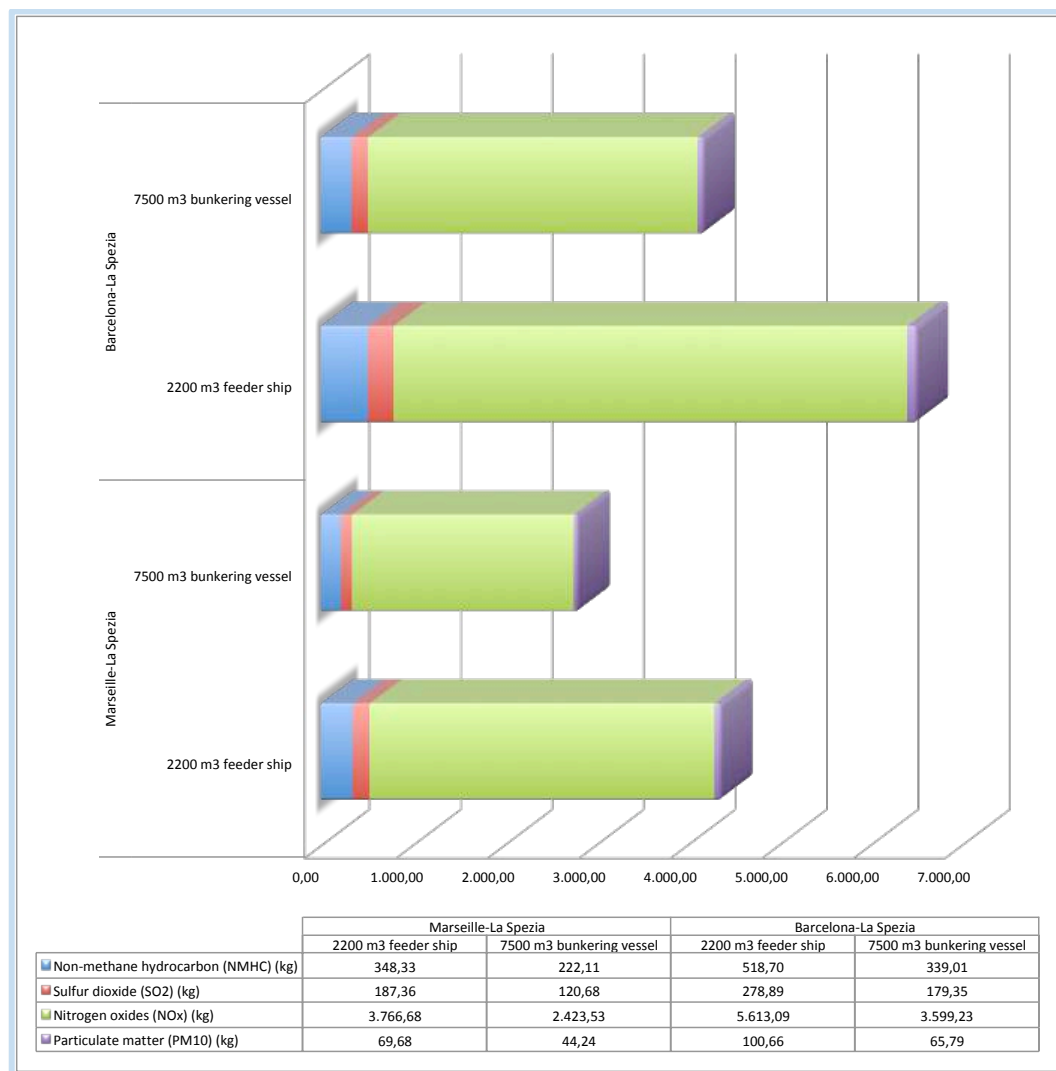


Figure 106 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG waterborne transport to supply LNG to La Spezia from existing terminals via 2.200 and 7.500 m³ feeder ships (MDO fuelled) loaded at full capacity on each trip, to cover the entire demand in the lower case scenario.

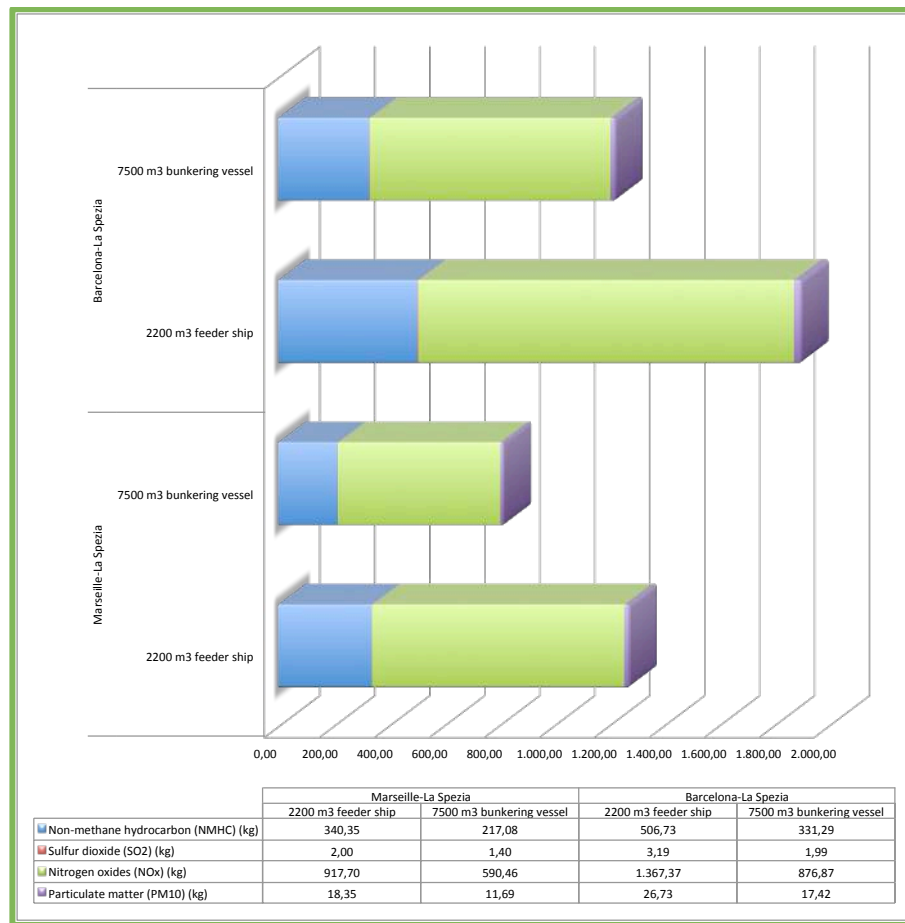


Figure 107 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG waterborne transport to supply LNG to La Spezia from existing terminals via 2.200 and 7.500 m³ feeder ships (LNG fuelled) loaded at full capacity on each trip, to cover the entire demand in the lower case scenario.

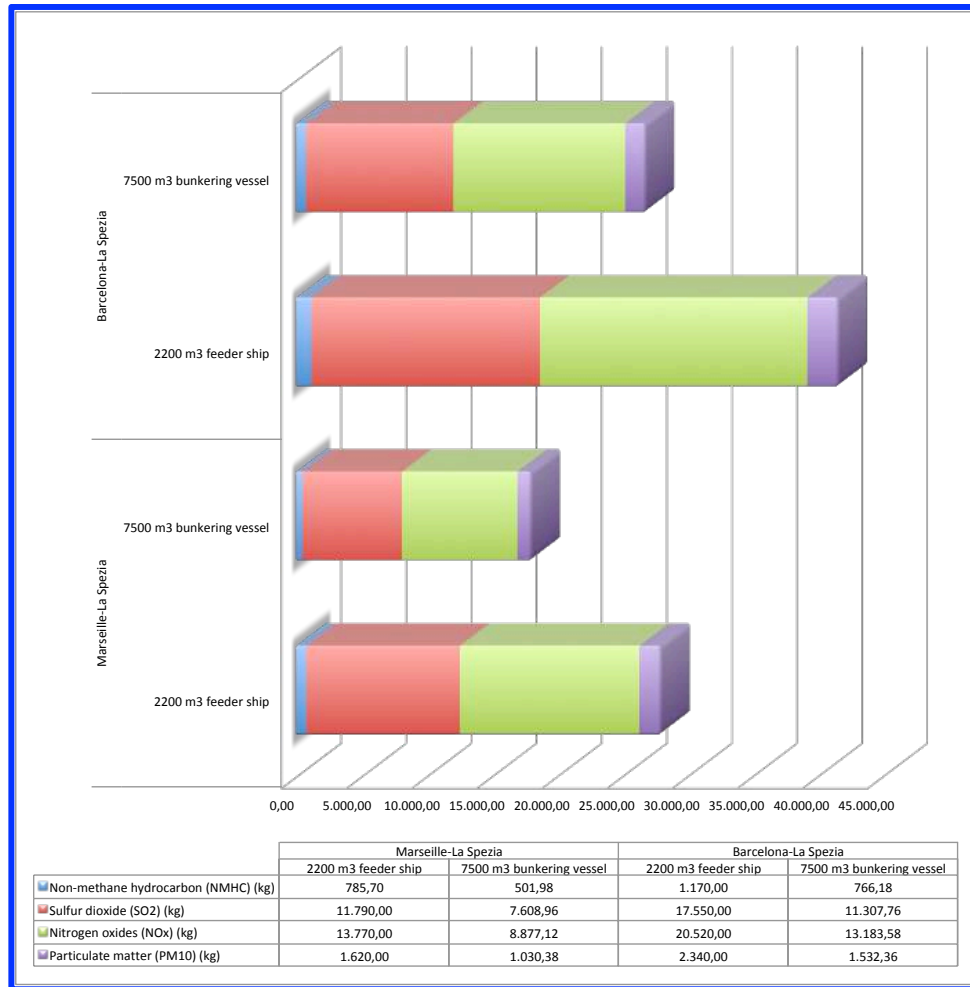


Figure 108 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG waterborne transport to supply LNG to La Spezia from existing terminals via 2.200 and 7.500 m³ feeder ships (traditionally fuelled) loaded at full capacity on each trip, to cover the entire demand in the higher case scenario.

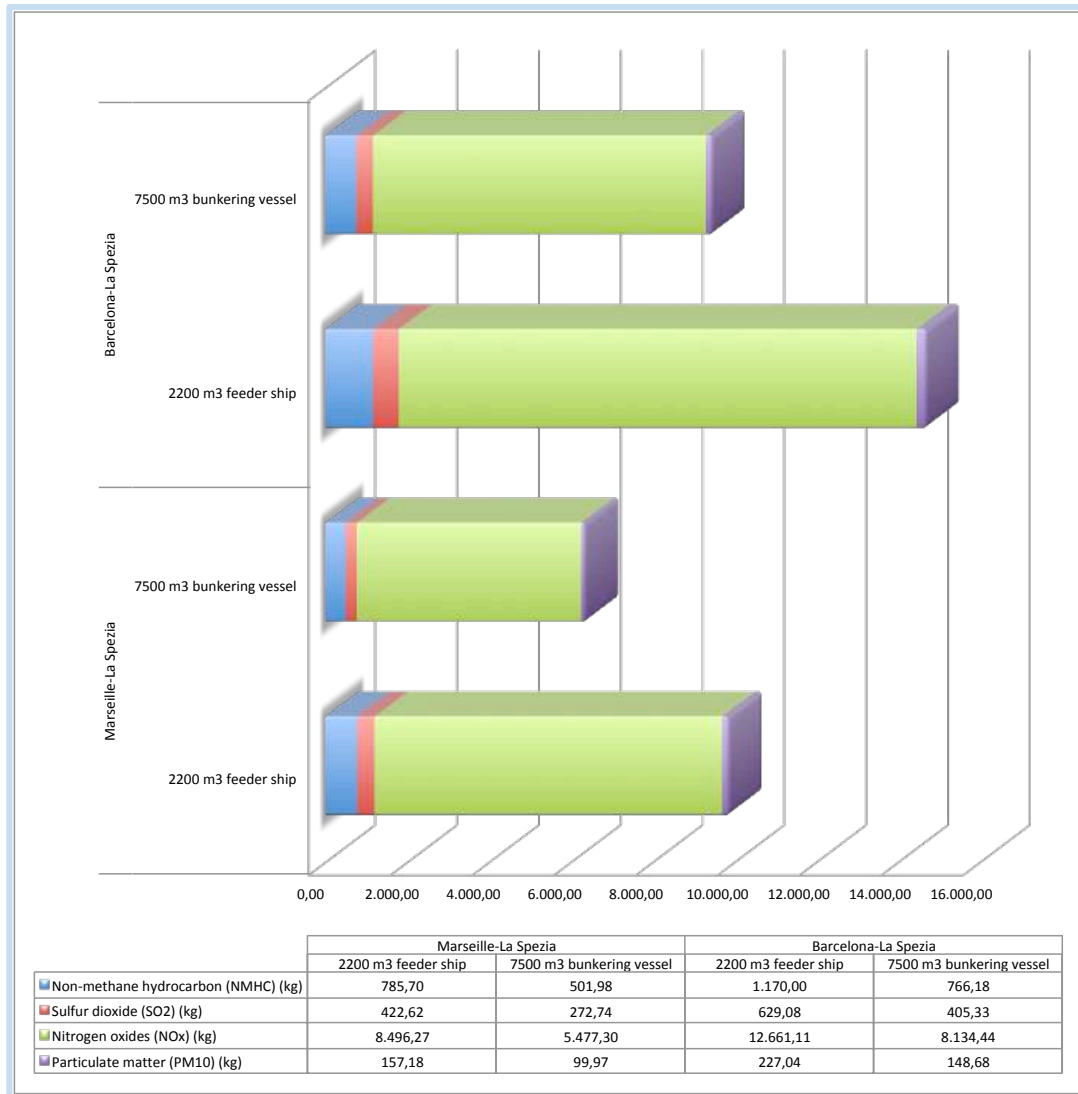


Figure 109 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG waterborne transport to supply LNG to La Spezia from existing terminals via 2.200 and 7.500 m³ feeder ships (MDO fuelled) loaded at full capacity on each trip, to cover the entire demand in the higher case scenario.

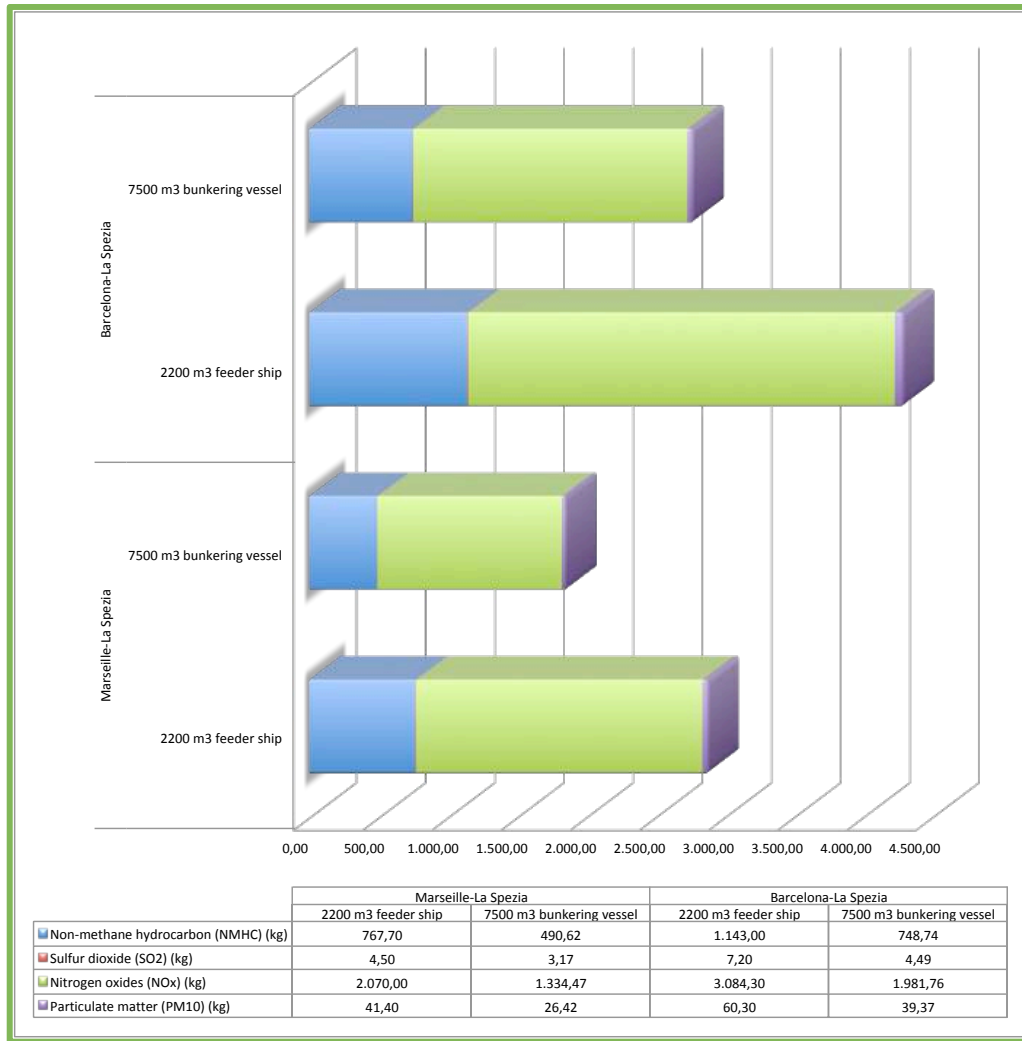


Figure 110 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG waterborne transport to supply LNG to La Spezia from existing terminals via 2.200 and 7.500 m³ feeder ships (LNG fuelled) loaded at full capacity on each trip, to cover the entire demand in the higher case scenario.

7.3.7 Waterborne transport's energy consumption, GHGs and air pollutants: single trips performances and elaboration with an eye towards estimations of the impacts to cover the entire LNG demand for the port of La Spezia from suitable planned terminals

The results to follow represent the further elaboration of the outcomes of the EcoTransit Tool-based simulation presented in Appendices B5 and B6 reported at the end of this document.

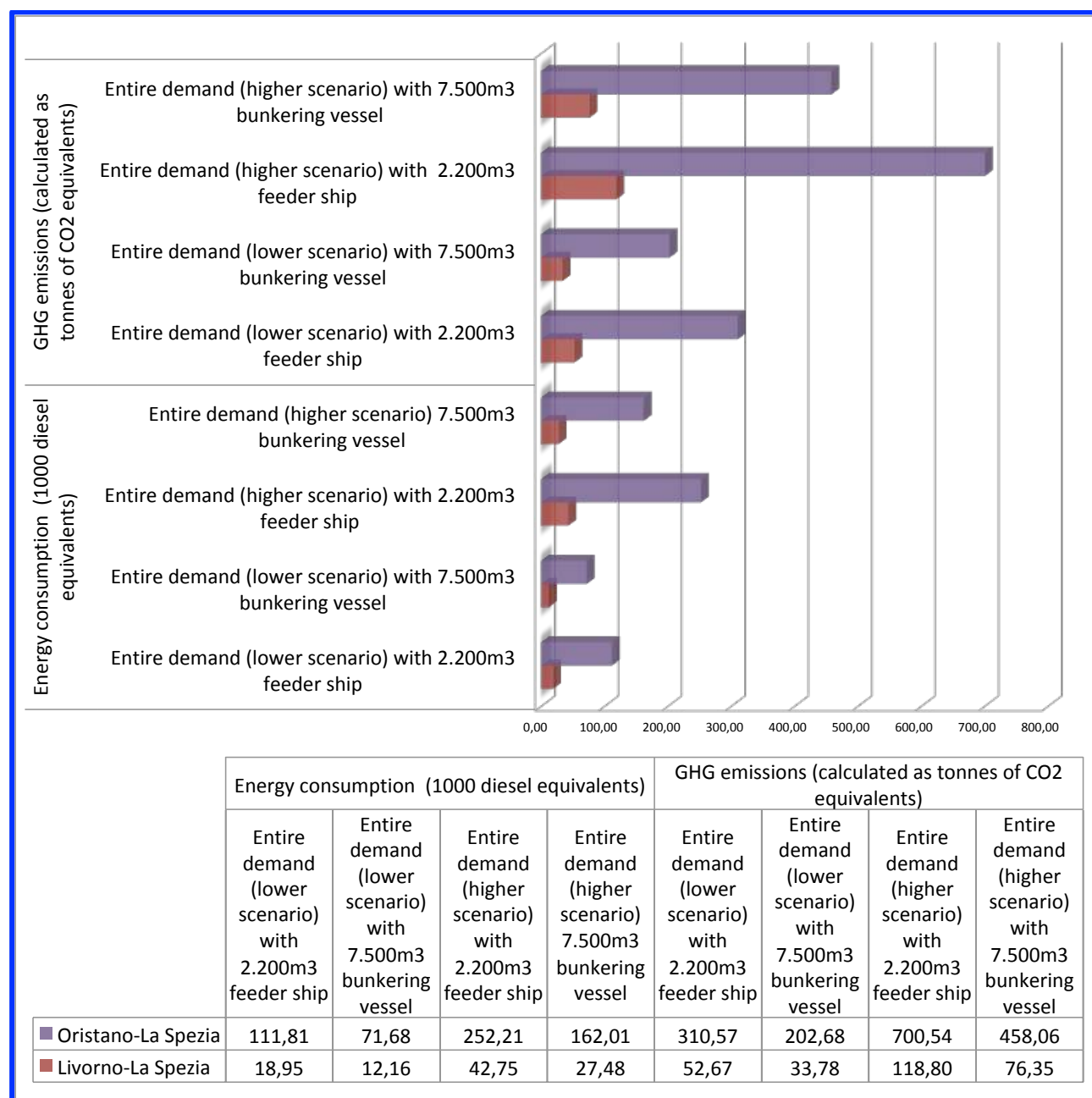


Figure 111 – LNG waterborne transport energy consumption (expressed as thousands of litres of diesel equivalents) and GHGs (expressed as tonnes of CO₂ equivalents) to cover the entire LNG annual demand of the Port of La Spezia from suitable planned terminals in the lower and higher case scenarios, via 2.200 and 7.500 m³ feeder ships (traditionally fuelled) loaded at full capacity.

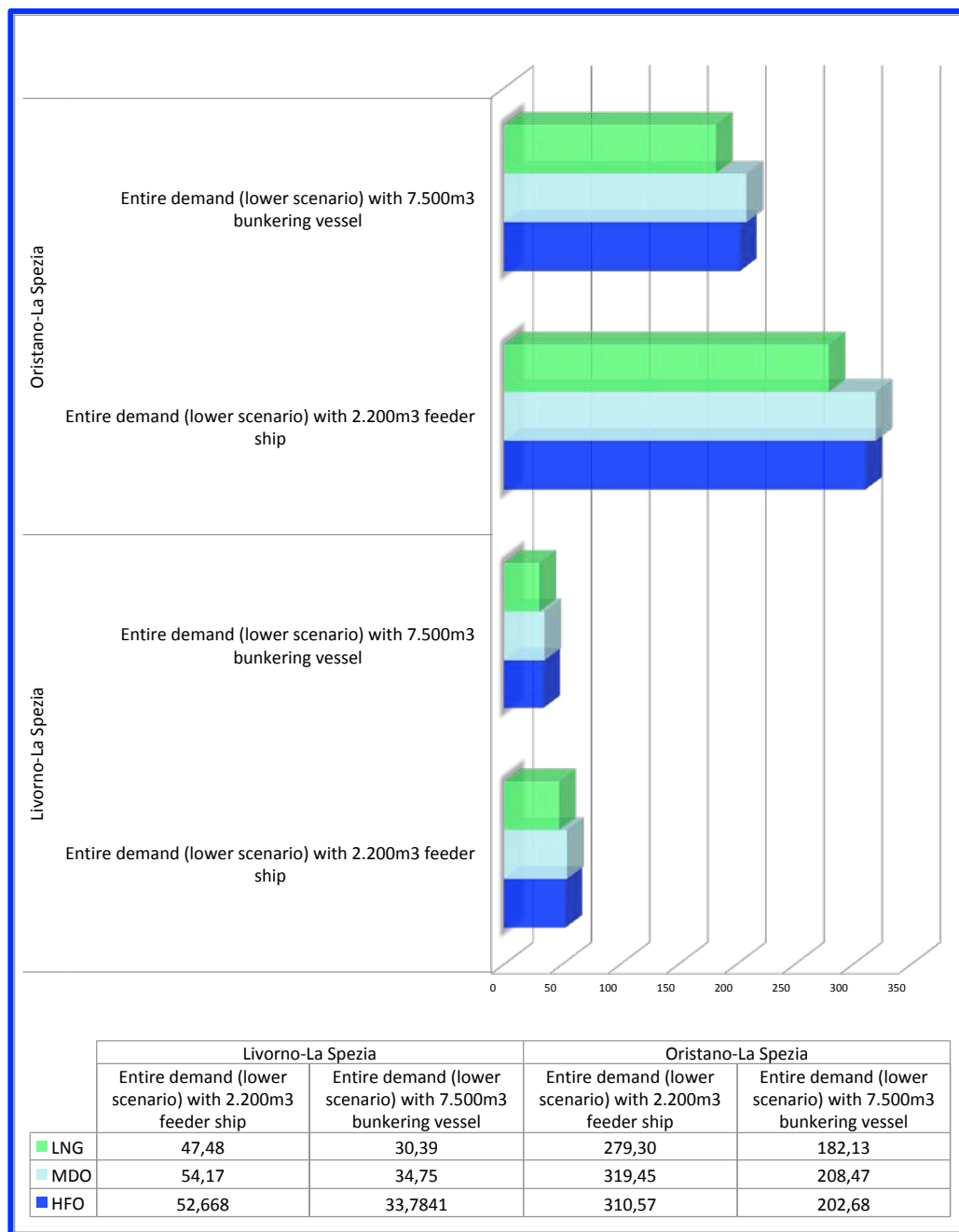


Figure 112 – Comparison of maritime fuels performances: GHGs (expressed as tonnes of CO₂ equivalents) to cover the entire LNG annual demand of the Port of La Spezia from suitable planned terminals in the lower case scenario, via 2.200 and 7.500 m³ feeder ships loaded at full capacity and fuelled by traditional fuel (mainly HFO), MDO and LNG.

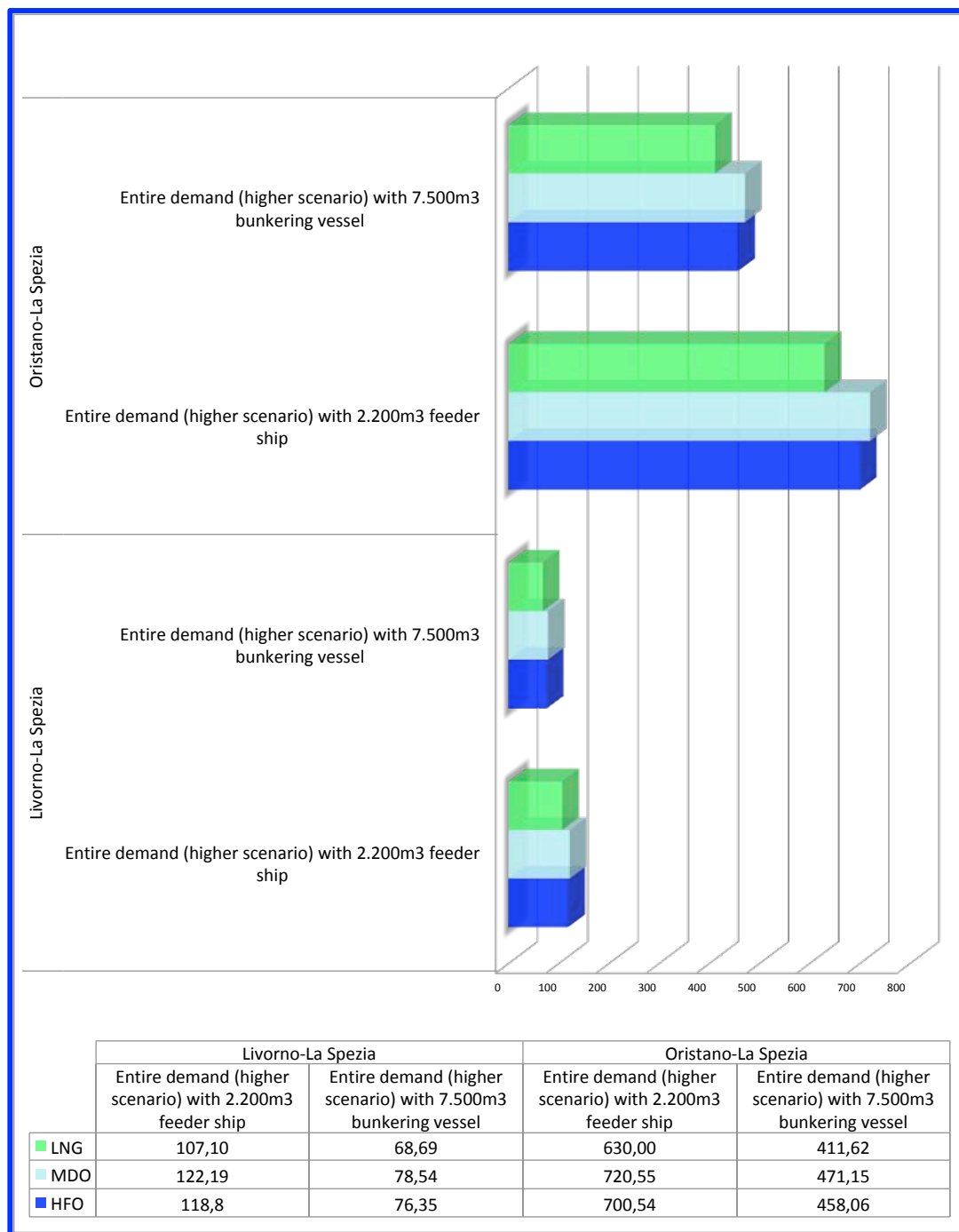


Figure 113 – Comparison of maritime fuels performances: GHGs (expressed as tonnes of CO₂ equivalents) to cover the entire LNG annual demand of the Port of La Spezia from suitable planned terminals in the higher case scenario, via 2.200 and 7.500 m³ feeder ships loaded at full capacity and fuelled by traditional fuel (mainly HFO), MDO and LNG.

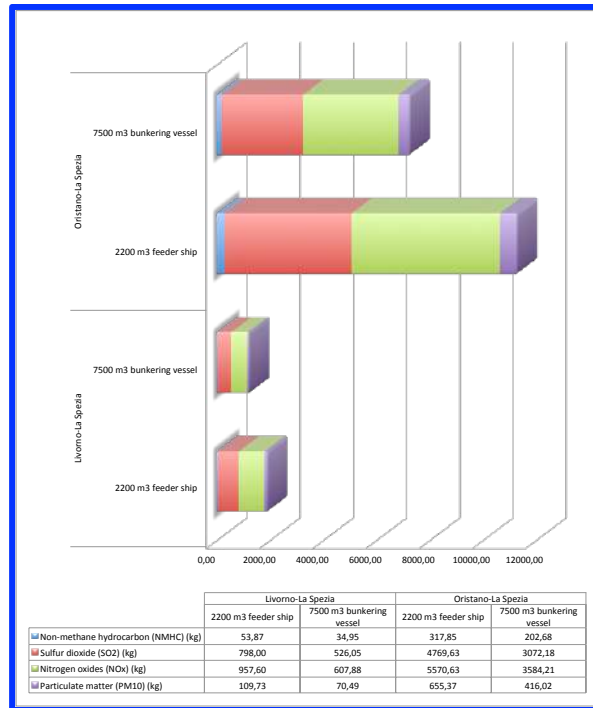


Figure 114 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG waterborne transport to supply LNG to La Spezia from suitable planned terminals via 2.200 and 7.500 m³ feeder ships (traditionally fuelled) loaded at full capacity on each trip, to cover the entire demand in the lower case scenario.

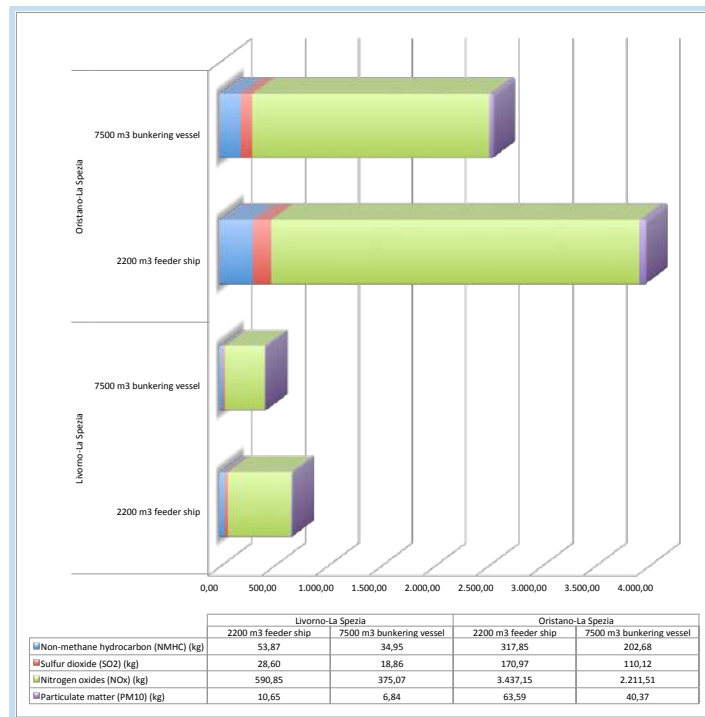


Figure 115 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG waterborne transport to supply LNG to La Spezia from suitable planned terminals via 2.200 and 7.500 m³ feeder ships (MDO fuelled) loaded at full capacity on each trip, to cover the entire demand in the lower case scenario.

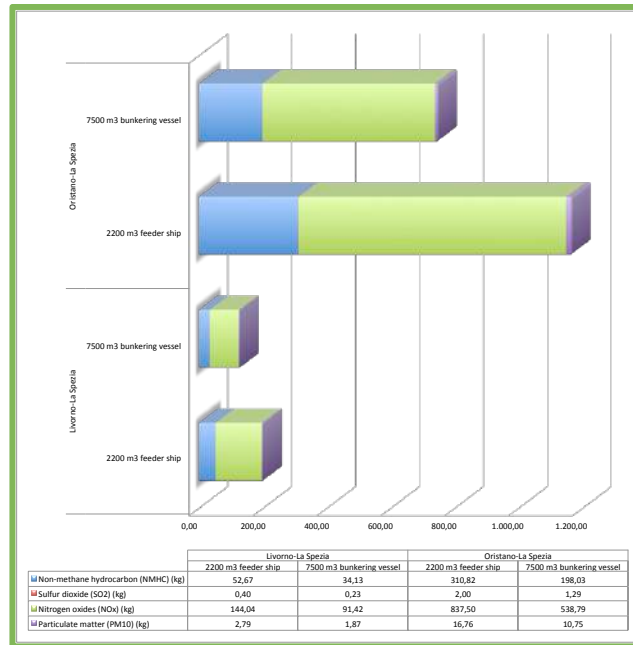


Figure 116 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG waterborne transport to supply LNG to La Spezia from suitable planned terminals via 2.200 and 7.500 m³ feeder ships (LNG fuelled) loaded at full capacity on each trip, to cover the entire demand in the lower case scenario.

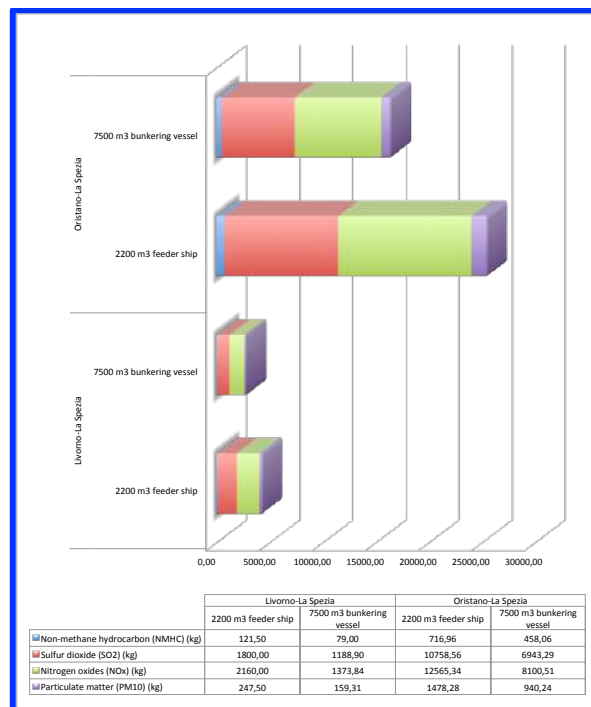


Figure 117 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG waterborne transport to supply LNG to La Spezia from suitable planned terminals via 2.200 and 7.500 m³ feeder ships (traditionally fuelled) loaded at full capacity on each trip, to cover the entire demand in the higher case scenario.

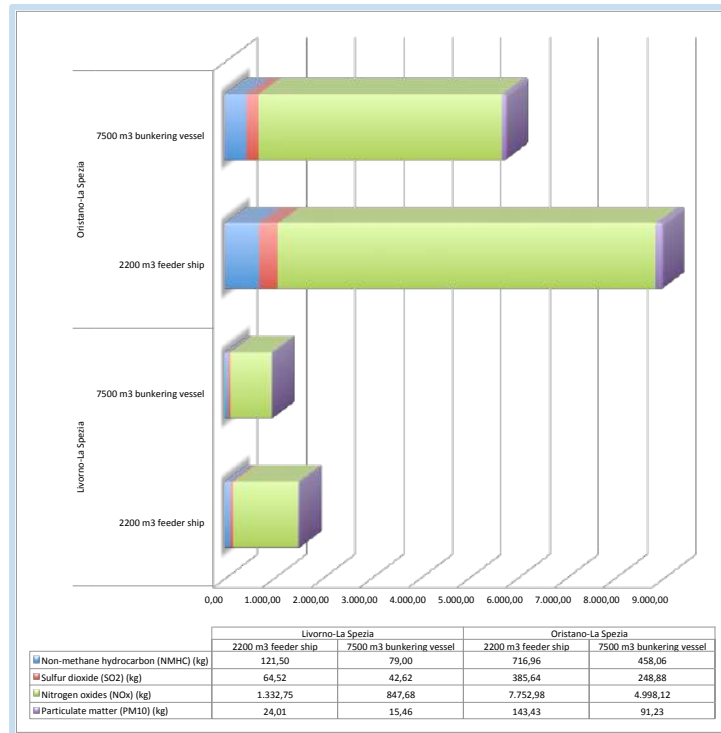


Figure 118 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG waterborne transport to supply LNG to La Spezia from suitable planned terminals via 2.200 and 7.500 m³ feeder ships (MDO fuelled) loaded at full capacity on each trip, to cover the entire demand in the higher case scenario.

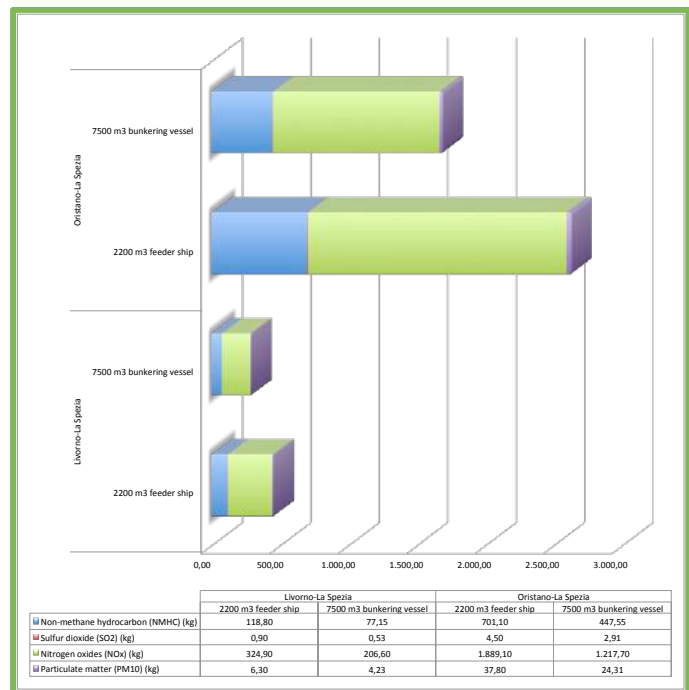


Figure 119 – Air pollutants distribution and accounting (expressed in tonnes of pollutant generated) related to LNG waterborne transport to supply LNG to La Spezia from suitable planned terminals via 2.200 and 7.500 m³ feeder ships (LNG fuelled) loaded at full capacity on each trip, to cover the entire demand in the higher case scenario.

8 Overall discussion

Considerations on intermodal transport of ISO-containers

According to the simulations, the potential for an optimized LNG supply chain may rely on intermodality. ISO-containers certainly allow for this opportunity to be further explored. Yet, a reliable supply chain seems not to exist in this case. Actually, both the transport of LNG via railways and in containerized units loaded onboard ships are at a piloting stage.

To make a few of the most recent and pertinent experiences in this regard occurred in the last year in the West Med Area, the previously cited GAINN4MED Action started in 2018 to carry out real life trials of the Project's LNG network and related logistics. In particular, with regard to operational testing of the mobile-infrastructure-based supply chain, Consorzio 906 in collaboration with Grimaldi as a stakeholder, carried out a pioneering multimodal shipment of ISO-container for LNG making best use of the Motorways of the Sea. The trial took place on the Barcelona-Livorno route. In the Tuscan port, the ISO tank was embarked empty and without a trailer on a Grimaldi Lines' Ro-Ro ship. Unloaded in Barcelona, it was picked up by a Spanish hauler to be filled with LNG at the Enagas terminal and then returned to the boarding area. Once again loaded on the ship, it came back to the port of Livorno from which it was towed by an Italian hauler to unload its cryogenic load at a C-LNG road refueling station located in Ancona.

This test is a first-of-a-kind in the Mediterranean. We are talking about the first intermodal transport on routes belonging to the Motorways of the Sea, of which GAINN4MED is validating the concept while expressing its operational potential.



Figure 120 – Trailer with ISO-container on quay waiting to be loaded (left) and unloaded (right) from a Ro-Ro ship during a pilot application (GAINN4MED Project) on the Barcelona-Livorno route.

The test allowed to experiencing obstacles and opportunities of this type of logistic solutions. Many issues are in fact to be addressed: from the correct application of the regulations on intermodal transport (ruled at EU level by Directive 2015/719 and regulated in Italy by circular 300/A/2536/18/108/5/1 of the Ministry of Interior) to the temporary storage of cryogenic units within ADR areas (dangerous goods) in ports, passing through the systematization of a combined transport that, so far, is unprecedented.

The next trials are under definition, with a soft spot on the central-southern Italy, where the LNG infrastructure is less developed. In this context, the opportunity of involving the ports of Salerno and Messina and the dual-fuel ELIO Ro-Pax ship launched by Caronte & Tourist, the first LNG ferry in the Mediterranean, is particularly relevant and shall be followed with interest.

Even more recent is the experience gained within the CORE LNGas hive project successfully carried out the first pilot test of multimodal transport of liquefied natural gas (LNG) in Europe. The initiative has consisted of transporting LNG in an ISO-container from Huelva to Melilla, by road, rail and sea.

The LNG was loaded into the ISO-container at the Enagás Regasification Plant located in the Port of Huelva. From there, it was transported by truck to the Huelva Port Railway Terminal, where it was transferred on a train. The train travelled to Majarabique station (Seville), and from there it was transported by truck to the Port of Algeciras (Cadiz). There, it was transferred to a vessel which made the journey from Algeciras to Melilla.

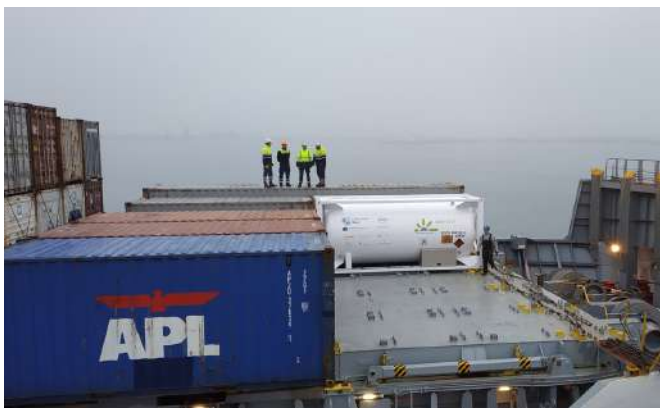


Figure 121 – Multi-modal transport by ship (left) and rail (right) of LNG ISO container, carried out within the EU CORE LNGas Hive project

This pilot test demonstrated the effectiveness of the ISO-container as a versatile and flexible solution for transporting natural gas. It facilitates the loading and unloading of LNG and can be easily handled from one means of transport to another, allowing the gas to travel long distances in a faster and safer manner. At the same time, it highlights the efficiency of the railway as a new key logistics solution to respond

competitively to the growing demand for alternative fuels. This opens up the possibility that new locations and markets could access LNG.

Tests such as those described above are certainly encouraging and suggest two considerations applicable to the case study presented here:

- Rail transport of LNG is at an infancy stage, and the same is said for LNG transport in containerized units loaded onboard ships: this makes the results regarding the simulations on costs, transit time, energy efficiency and air emissions less relevant, appealing and realistic for these particular transport mode;
- Investments, commercial agreements and economies of scale could change the way LNG is transported, boosting intermodality and realizing a remarkably interesting potential.

Considerations on LBVs market roll-out

Different is the case of another kind of LNG “mobile infrastructure”, which is far from being at piloting stage, while is rapidly experiencing a roll-out phase, namely the LBVs (LNG Bunkering Vessels).

In this regard it has to be recalled that real life LNG ship-to-ship (STS) bunkering in the EU is now in its sixth year, since the 180-m³ LNG bunker vessel (LBV) Seagas, a converted small Norwegian ferry, entered into service in the Port of Stockholm in 2013 to fuel the passenger/car ferry Viking Grace with 70 tonnes of LNG 4 days per week.

Name (or owner)	Delivery date	Capacity (m³)
<i>Seagas</i>	2013	180
<i>Engie Zeebrugge</i>	2017	5,000
<i>Cardissa</i>	2017	6,500
<i>Coralius</i>	2017	5,800
<i>Oizmendi</i>	2018	600
<i>Coral Methane</i>	2018	7,500
<i>Kairos</i>	2018	7,500
<i>Clean Jacksonville</i>	2018	2,200
<i>FlexFueller1</i>	2018	760
Stolt-Nielsen Gas	2019	7,500
Stolt-Nielsen Gas	2019	7,500
Korea Line	2019	7,500
Korea Line	2019	7,500
Victrol/CFT	2019	3,000
Total/MOL	2020	18,600
Q-LNG	2020	4,000
FueLNG	2020	7,500
CLS Japan	2020	3,500

Yet, until 2017, Seagas remained the sole practitioner of this method of fuelling LNG-powered ships. It was only in that year that the new LBV era really began to take hold, when the first three purpose-built LNG fuellers entered service, namely: the Zeebrugge-based 5.000 m³ Engie Zeebrugge; the 6.500 m³ Cardissa in Rotterdam and the 5.800 m³ Coralius, serving in the western Baltic Sea.

These and the many other LBV newbuildings set to follow, are enabling the growing fleet of gas-powered ships to be fuelled in a safer and more timely and efficient manner than is possible with jettyside truck-to-ship LNG transfers.

2017 was also notable for the newbuilding contracts for four 7,500-m³ coastal LNG carriers, also being able of offering STS bunkering services, comprising two for Korea Line and two for Stolt-Nielsen Gas, and all scheduled for 2019-2020 completions.

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During the first five weeks of 2018 an LBV almost three times the size of any such vessel yet built was ordered, while the first Spanish LNG STS fuelling operation, utilising a newly converted bunker barge, was carried out in Bilbao.

In February 2019, the 7.500-m³ LBV Kairos that Korea's Hyundai Mipo yard built for Babcock Schulte Energy, a Bernhard Schulte Shipmanagement/Babcock International joint venture, was christened at the Hamburg Cruise Center, becoming the world's largest LNG bunker supply vessel, being used to bunker large ocean-going vessels in the Baltic region and Northwest Europe.



Figure 122 – LGV Kairos Supplies LNG in 1st STS Bunkering operation for Wes Amelie. Worldmaritimenews.

As the 2019 goes along, LBV fleet developments continued apace, and the trend is expected to grow steadily, since for the large dual-fuel ships on quick port turnaround timetables now entering service, LBVs are recognised as the only viable option.

It is believed that the entry into service of the Stolt Nielsen's first LBV in the Mediterranean will become a game changer and will set the precedent for other such investments, most likely also in Italy and in the Tyrrhenian Ligurian basin, complementing the other coastal assets such as new modular storage facilities (Livorno at the helm in the timeline, but it may be the case of La Spezia as well) and existing regasification plants upgraded to offer SS LNG services (firstly OLT offshore, may be followed by Panigaglia).

Real life considerations on LNG supply

Being understood the above, and in addition to the considerations on costs, transit time, energy consumption and air emissions, there are other elements that shall be taken in due account to come up with a realistic supply and bunkering scenario from a practical point of view.

Although there is no clear evidence in literature, the emerging of the SS LNG market is rising a number of issues related to fiscal aspects of the LNG transfer operations, in particular as far as the STS bunkering option is concerned. If the unloading of a LNG feeder vessel to a coastal storage plant in a single operation is already ruled and does not pose significant problems, the case of a large bunkering ship which may discharge part of the cargo during a STS operation in one port and wants to undertake another STS bunkering operation without returning to the supply point is somewhat different. At present, informal talks of the author with PAAs and Custom Agency representatives suggest that this multiple operation would not

be allowed. On the contrary, a STS operation followed by a STT operation may be feasible, suggesting that the existence of satellite coastal storages may be required.

Another issue is of practical nature. Given that a SS bunkering system directed on a quay dedicated to cruise operations is unfeasible because of security reasons and spatial issues, while SIMOPS (simultaneous operations) encompassing STS bunkering and passenger embarkment/disembarkment is already a reality.

Opportunities and assets for the future LNG scenario in the Port of La Spezia

In this framework, the most likely scenario for La Spezia is that of counting on two flexible assets:

1. The modular storage envisaged to be located at Terminal Ravano, which as per sizing and location hypothesis described in Chapter 5, would allow the Port of La Spezia to scale its project and costs over time with the following main advantages:
 - Serve immediate off-takers and expand plant capacity as demand grows;
 - Reduce the plant's planning, engineering, permitting and construction schedule;
 - Reduce CAPEX while allowing for a quicker ROI starting generating revenues faster;
 - Reduce operational risk.

Yet, it is worth recalling that such a facility would be likely still supplied from a large LNG terminal (e.g. Marseille-Fos may continue to be in the first line for this kind of service) to cover a large proportion of the needed volumes, while a smaller fraction of the LNG needed to cover the entire annual demand may come from closer sources, such as Livorno via ISO-tanks transported by rail or via road tanker trucks.

2. An LNG bunkering vessel to be shared among the ports of the Tyrrhenian Ligurian Basin, with appropriate storage capacity (the size of 7.500m³ is, according to orderbook's and market's evolutions seems to fit the purpose) and which could allow STS bunkering even to the largest cruise ships, eventually unloading part of the cargo to the modular storage facility itself.

Replicability of the concept and target addressees

Given the flexibility and proven reliability of the proposed concept for modular SS storage and local distribution plant envisaged for the port of La Spezia, it is believed that the such concept's development could contribute strength the argument in favour of such concept's replicability in other ports and locations in the Tyrrhenian Ligurian basin, in the Italian Peninsula and in the Med Area.

Being understood that the reproducibility of the calculation methodology is essential to provide a clear allocation of emissions related to physically complex scenarios, the viability of a proven tool such as EcoTransit was tested and provided interesting outcomes. With this in mind, the research object of this document addresses:

- Future owners/managers of the LNG Small Scale facility in the Port of La Spezia willing to reduce the environmental impact of their LNG supply;
- Carriers, LNG suppliers and logistic providers being confronted with growing requests from customers as well as legislation to show their carbon footprint and improve their logistical chains from an environmental perspective;
- Political decision makers, maritime and port authorities, consumers and non-governmental organisations which are interested environmental comparisons of supply concepts including all applicable transport modes (lorry, railway, ship, and combined transport), covering an array of environmental parameters that spans from energy consumption, greenhouse gases (measured as CO₂ equivalents) and air pollutants such as nitrogen oxides (NO_x), sulphur dioxide (SO₂), non-methane hydro carbons (NMHC) and particulate matter (PM).

9 Conclusions

This paper offered a focus on a particular case study, while at the same time broadening the scope of investigation by providing insights on the trends on Small Scale bunkering services.

Stemming from the knowledge and experience gained within the course of EU-funded trans-national projects, this study focused on investigating the critical aspects (from an environmental, energy and economic point of view) of the LNG supply chain for the Port of La Spezia (Italy).

The local context has been investigated in terms of existing assets, applicable regulations and logistic constraints.

The potential demand for LNG in the Port of La Spezia has been considered and elaborated grounding on publicly available data and model validated within the GAINN_IT Initiative.

The existing SNAM owned and GNL Italia operated regasification terminal of Panigaglia has been analysed in detail, evaluating the upgrading needed to provide Small Scale LNG services in an evolving framework, while elaborating location and sizing hypotheses for an alternative modular LNG storage layout within the Port of La Spezia.

Different scenarios for ensuring adequate supply to cover the entire LNG demand have been studied considering the existing supply sources in Europe, resulting in simulations on costs and transit time for supplying of LNG from selected terminals of origin and assessments of supplying of LNG by barge from Panigaglia or by tanker from international terminals through different pathways.

Supplying scenarios related the latest evolutions in terms of LNG infrastructure deployment at national level have been then considered, serving as a basis for undertaking simulations on the energy consumption, GHGs and air pollutants emissions generated to supply La Spezia from both existing and suitable planned terminals.

As a result, the paper looks into the overall aspects of the small scale LNG chain in the Port of La Spezia from a technical, energy, environmental and economical point of view, providing insights to further detailed industrial studies aimed at setting up the most suitable supply chain for LNG deployment in the area.

Conclusions on LNG Small Scale services' development in the investigated area

Experiencing considerable growth, with climate change very much on policy and industry agendas, the use of LNG as a fuel for ships is an excellent solution to meet the new emission targets coming into force.

Industry pioneers in the Med Area and in the Tyrrhenian Ligurian basin that are investing in Small Scale plants and solutions will inspire others to follow.

Improvements to project economics are expected from standardisation and modularisation of production facilities. The Small Scale LNG business opens the possibility to implement and deploy more challenging LNG technology concepts more quickly and cost-effectively, which can benefit the conventional large-scale LNG industry as well.

Large-scale LNG export terminals, in fact, will continue to play an important role in contributing to the growing Small to Mid-Scale LNG markets, covering the needs of emerging plants and ensuring cost-efficient

supply solutions. For the study case of the Port of La Spezia, the already in place facility at Marseille Fos-sur-mer will certainly be a reliable source of supply, even more when considering the upgradings and respective investments which are expected to be completed in the forthcoming future.

Conclusions on the strategic advantages on introducing LNG as a fuel in Italy and in the area

The main strategic aspects for LNG deployment in road and maritime transport in Italy can be summarized as follows:

- reduction of pollutants such as NO_x, SO_x and CO₂ and noise emissions;
- possibility of more energy efficient solutions, for example through use of chilled water for air conditioning and for industrial cooling processes;
- possibility of using a less polluting fuel in those areas not yet reached by the National Gas Pipeline Network
- greater economic efficiency for naval transport compared to conventional fuels;
- industrial development especially in the naval sector with consequent modernization of the fleet, construction of new small LNG carriers and development of port areas
- boosting the modularity and flexibility of Small Scale LNG technologies
- enhancement of existing infrastructures (see regasification terminals)

Decisive factors for the development of the plan are considered: the simplification of the legislation on authorization procedures, the identification of appropriate economic incentives, greater stability of the tax system, social acceptability and security.

La Spezia and the Thyrrenan Ligurian LNG system hold the potential to answer the call.

Criticalities and conditions for overcoming them

The infrastructure gap in the first ring of the LNG downstream is the main criticality for the development of the supply chain:

- The Italian terminals do not allow the loading of tankers that deliver the LNG to the final users. realization of operational coastal deposits between 2019 and 2020
- Construction of the first Italian facility for loading SSLNG tankers and / or bunkership at the OLT terminal

- The entry into operation of SSLNG bunker ship and LNG tankers should take place at the same time and may also have a base in other Mediterranean ports

An essential condition for the development of the LNG SS bunkering market is the willingness of operators to invest in bunkering vessels intended as mobile infrastructure for the supply of LNG ship to ship.

This study also confirms that this, beside rail transport when properly rolled-out, will deliver the greatest advantages in terms of flexibility, cost effectiveness, energy efficiency and environmental performances.

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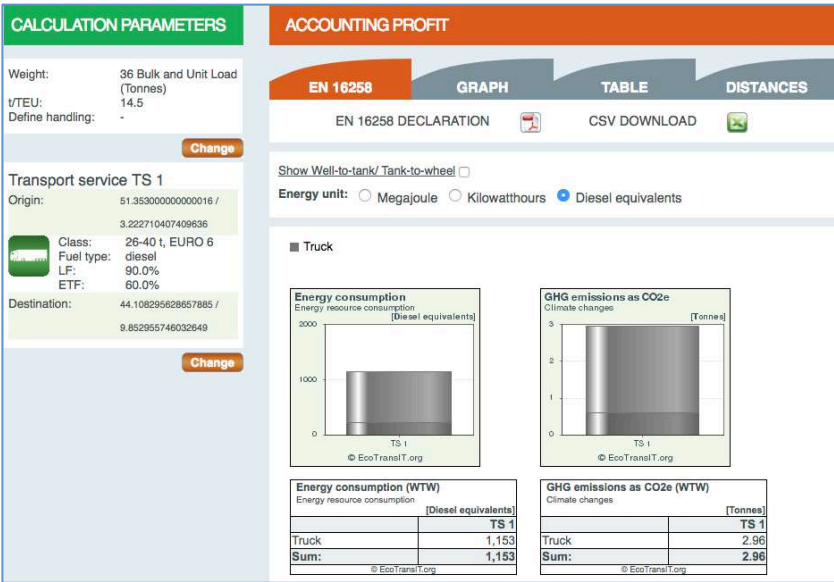
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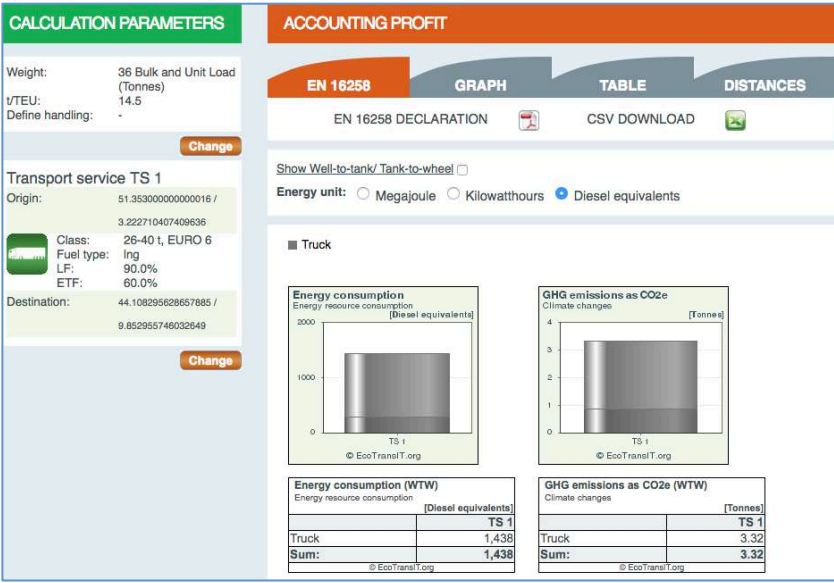
**Appendix A – EcoTransit LNG transport simulation results on
single trips from existing LNG terminals.**

A1 - Energy consumption and GHGs related to LNG road transport to supply La Spezia from existing terminals using diesel or LNG as a truck fuel.

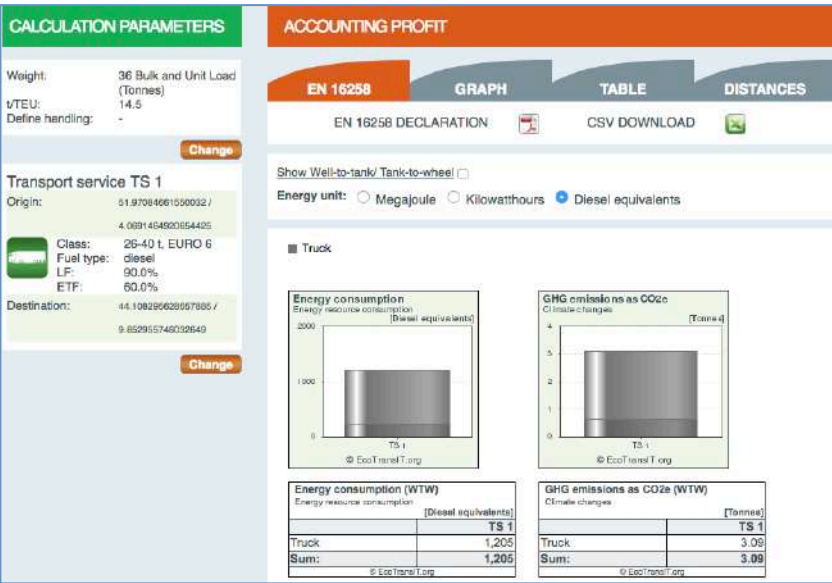
Zeebrugge – La Spezia



Energy consumption and GHGs related to LNG road transport to supply La Spezia from Zeebrugge using diesel as truck fuel (one way).



Energy consumption and GHGs related to LNG road transport to supply La Spezia from Zeebrugge using LNG as truck fuel (one way).

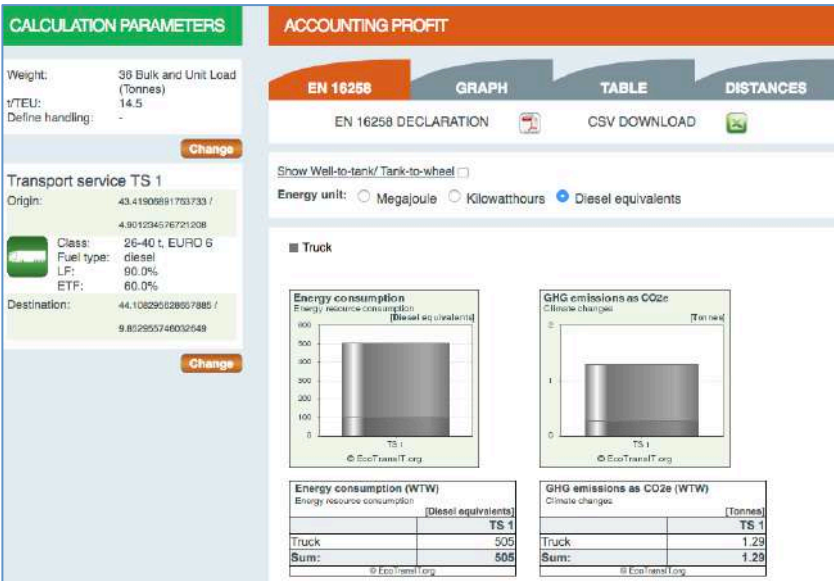


Energy consumption and GHGs related to LNG road transport to supply La Spezia from Rotterdam using diesel as truck fuel (one way).

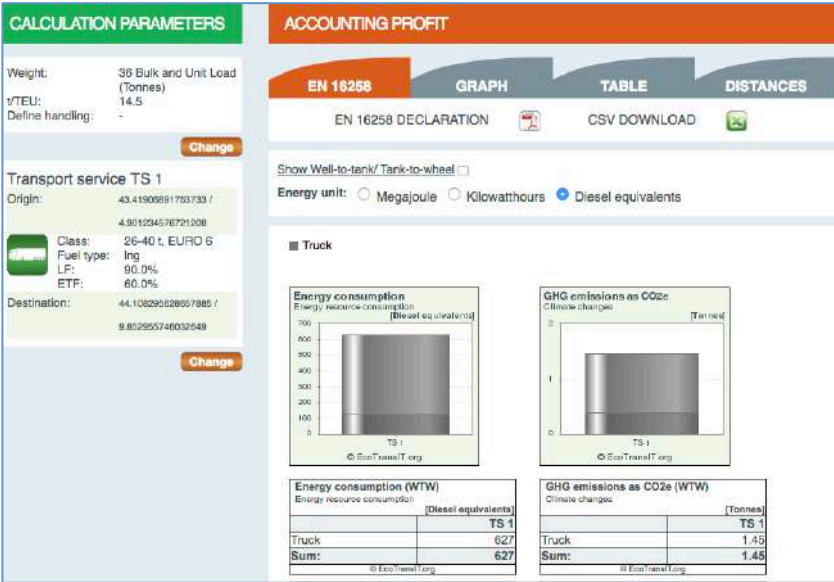


Energy consumption and GHGs related to LNG road transport to supply La Spezia from Rotterdam using LNG as truck fuel (one way).

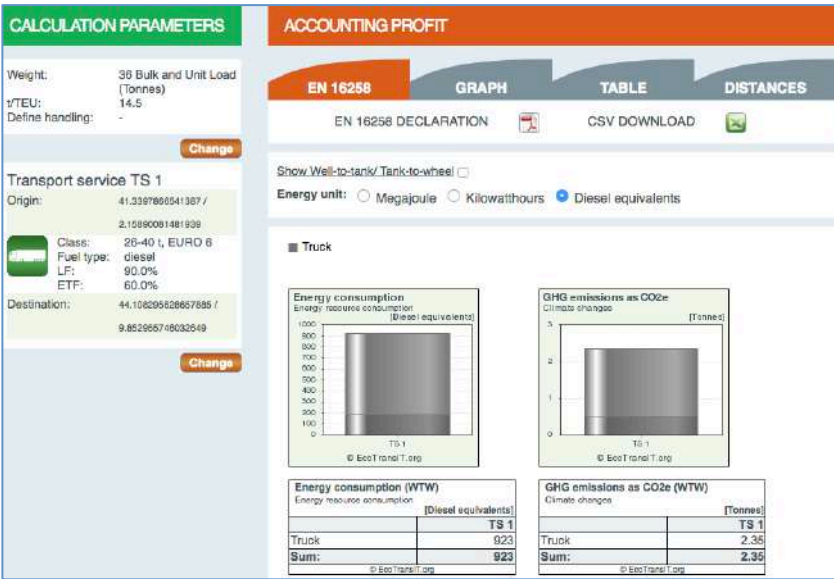
Marseille (Fos-sur-Mer) – La Spezia



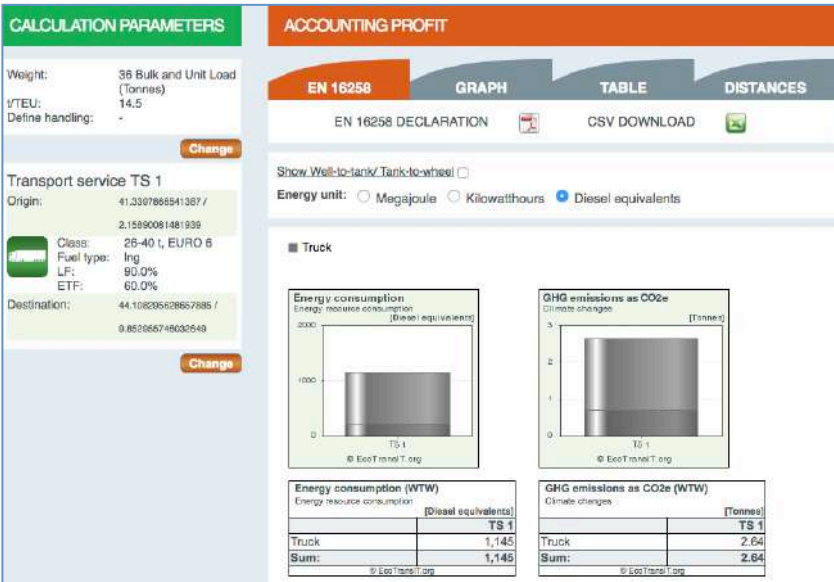
Energy consumption and GHGs related to LNG road transport to supply La Spezia from Marseille using diesel as truck fuel (one way).



Energy consumption and GHGs related to LNG road transport to supply La Spezia from Marseille using LNG as truck fuel (one way).



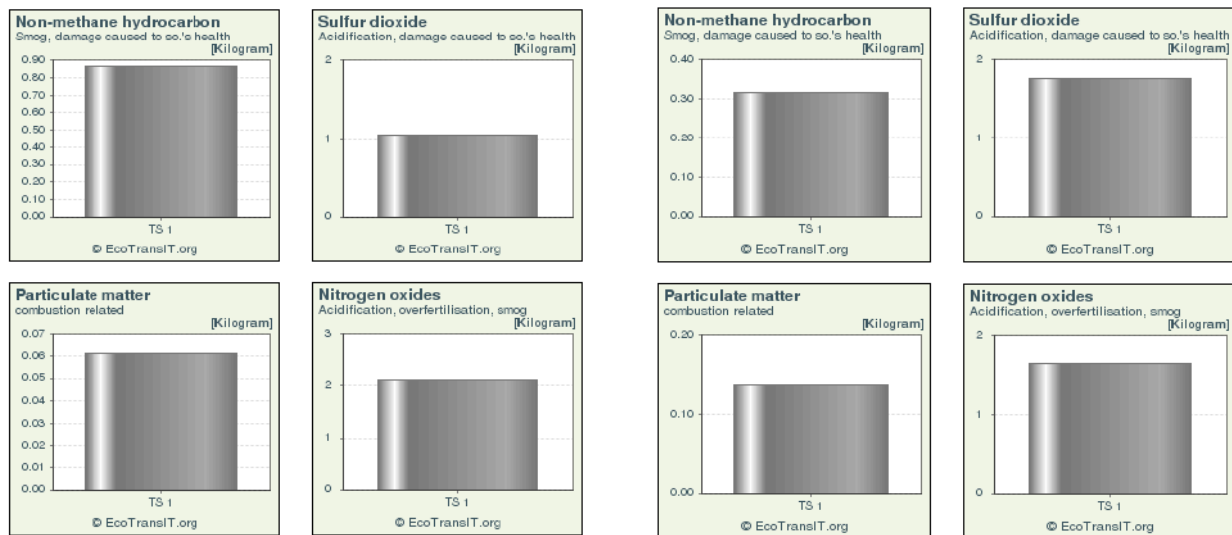
Energy consumption and GHGs related to LNG road transport to supply La Spezia from Barcelona using diesel as truck fuel (one way).



Energy consumption and GHGs related to LNG road transport to supply La Spezia from Barcelona using LNG as truck fuel (one way).

A2 – Air pollutants emissions related to LNG road transport to supply La Spezia from existing terminals using diesel or LNG as a truck fuel.

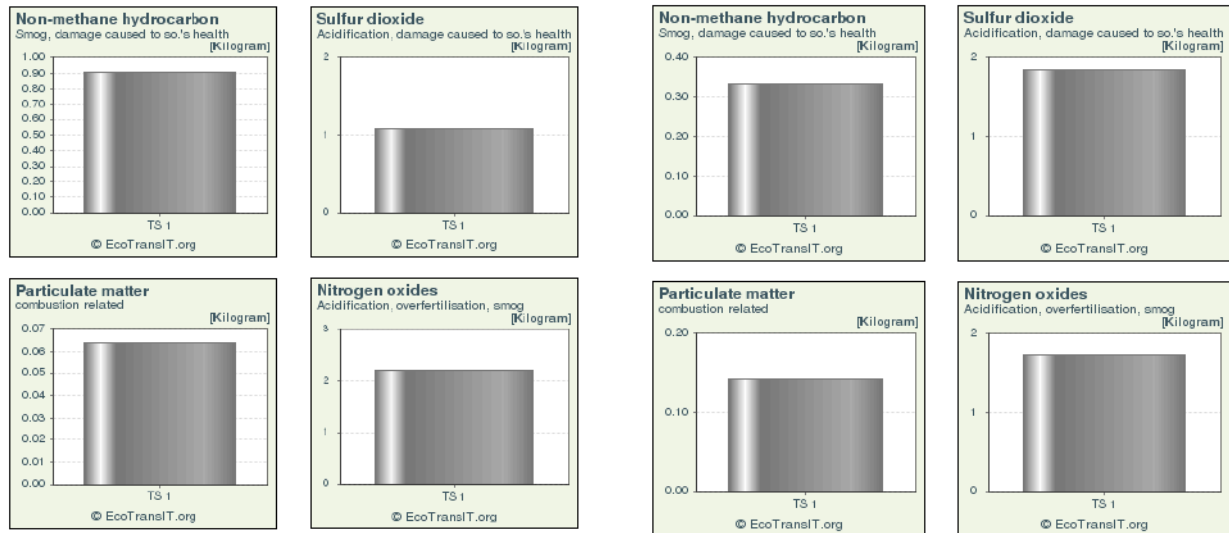
Zeebrugge – La Spezia



Charts of Air pollutants emissions related to LNG road transport to supply La Spezia from Zeebrugge using diesel (right) or LNG (left) as truck fuel (one way).

Non-methane hydrocarbon (WTW) Smog, damage caused to so's health (kilogram) TS 1 Truck: 0.87 Sum: 0.87 © EcoTransit.org	Sulfur dioxide (WTW) Acidification, damage caused to so's health (kilogram) TS 1 Truck: 1.04 Sum: 1.04 © EcoTransit.org	Non-methane hydrocarbon (WTW) Smog, damage caused to so's health (kilogram) TS 1 Truck: 0.32 Sum: 0.32 © EcoTransit.org	Sulfur dioxide (WTW) Acidification, damage caused to so's health (kilogram) TS 1 Truck: 1.76 Sum: 1.76 © EcoTransit.org
Particulate matter (WTW) combustion related (kilogram) TS 1 Truck: 0.061 Sum: 0.061 © EcoTransit.org	Nitrogen oxides (WTW) Acidification, overfertilisation, smog (kilogram) TS 1 Truck: 2.11 Sum: 2.11 © EcoTransit.org	Particulate matter (WTW) combustion related (kilogram) TS 1 Truck: 0.14 Sum: 0.14 © EcoTransit.org	Nitrogen oxides (WTW) Acidification, overfertilisation, smog (kilogram) TS 1 Truck: 1.65 Sum: 1.65 © EcoTransit.org

Values of Air pollutants emissions related to LNG road transport to supply La Spezia from Zeebrugge using diesel (right) or LNG (left) as truck fuel (one way).



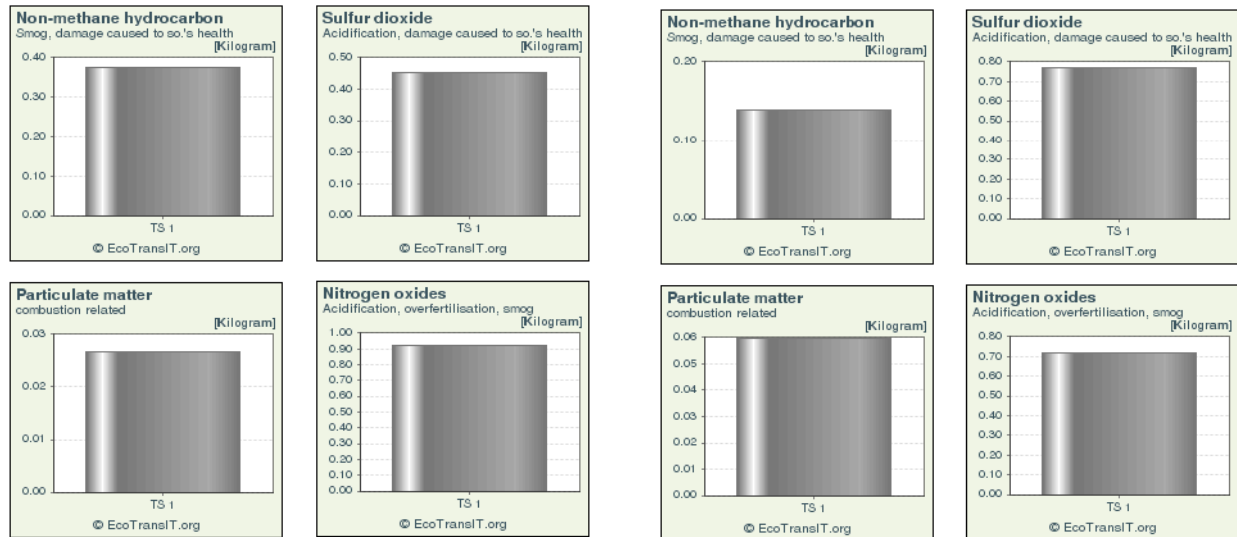
Charts of Air pollutants emissions related to LNG road transport to supply La Spezia from Rotterdam using diesel (right) or LNG (left) as truck fuel (one way).

Non-methane hydrocarbon (WTW) Smog, damage caused to so's health		Sulfur dioxide (WTW) Acidification, damage caused to so's health		Non-methane hydrocarbon (WTW) Smog, damage caused to so's health		Sulfur dioxide (WTW) Acidification, damage caused to so's health	
	(kilogram)		(kilogram)		(kilogram)		(kilogram)
	TS 1		TS 1		TS 1		TS 1
Truck	0.91	Truck	1.09	Truck	0.33	Truck	1.84
Sum:	0.91	Sum:	1.09	Sum:	0.33	Sum:	1.84
© EcoTrans1.org		© EcoTrans1.org		© EcoTrans1.org		© EcoTrans1.org	

Particulate matter (WTW) combustion related		Nitrogen oxides (WTW) Acidification, overfertilisation, smog		Particulate matter (WTW) combustion related		Nitrogen oxides (WTW) Acidification, overfertilisation, smog	
	(kilogram)		(kilogram)		(kilogram)		(kilogram)
	TS 1		TS 1		TS 1		TS 1
Truck	0.064	Truck	2.20	Truck	0.14	Truck	1.73
Sum:	0.064	Sum:	2.20	Sum:	0.14	Sum:	1.73
© EcoTrans1.org		© EcoTrans1.org		© EcoTrans1.org		© EcoTrans1.org	

Values of Air pollutants emissions related to LNG road transport to supply La Spezia from Rotterdam using diesel (right) or LNG (left) as truck fuel (one way).

Marseille (Fos-sur-Mer) – La Spezia

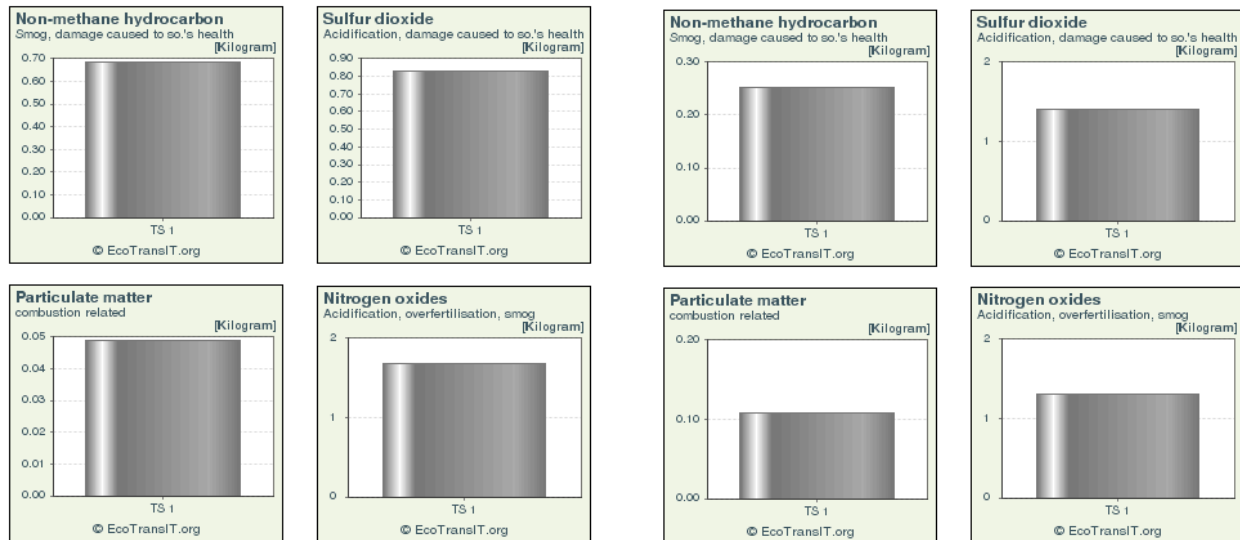


Charts of Air pollutants emissions related to LNG road transport to supply La Spezia from Marseille using diesel (right) or LNG (left) as truck fuel (one way).

Non-methane hydrocarbon (WTW) Smog, damage caused to so's health		Sulfur dioxide (WTW) Acidification, damage caused to so's health		Non-methane hydrocarbon (WTW) Smog, damage caused to so's health		Sulfur dioxide (WTW) Acidification, damage caused to so's health	
(kilogram)		(kilogram)		(kilogram)		(kilogram)	
TS 1		TS 1		TS 1		TS 1	
Truck	0.38	Truck	0.45	Truck	0.14	Truck	0.77
Sum:	0.38	Sum:	0.45	Sum:	0.14	Sum:	0.77
© EcoTransT.org		© EcoTransT.org		© EcoTransT.org		© EcoTransT.org	

Particulate matter (WTW) combustion related		Nitrogen oxides (WTW) Acidification, overfertilisation, smog		Particulate matter (WTW) combustion related		Nitrogen oxides (WTW) Acidification, overfertilisation, smog	
(kilogram)		(kilogram)		(kilogram)		(kilogram)	
TS 1		TS 1		TS 1		TS 1	
Truck	0.027	Truck	0.92	Truck	0.060	Truck	0.72
Sum:	0.027	Sum:	0.92	Sum:	0.060	Sum:	0.72
© EcoTransT.org		© EcoTransT.org		© EcoTransT.org		© EcoTransT.org	

Values of Air pollutants emissions related to LNG road transport to supply La Spezia from Marseille using diesel (right) or LNG (left) as truck fuel (one way).



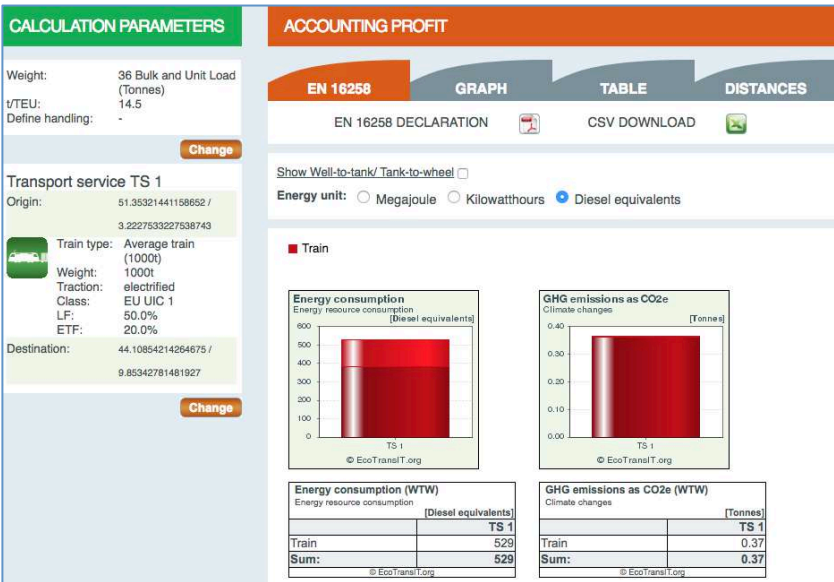
Charts of Air pollutants emissions related to LNG road transport to supply La Spezia from Barcelona using diesel (right) or LNG (left) as truck fuel (one way).

Non-methane hydrocarbon (WTW) Smog, damage caused to so's health		Sulfur dioxide (WTW) Acidification, damage caused to so's health		Non-methane hydrocarbon (WTW) Smog, damage caused to so's health		Sulfur dioxide (WTW) Acidification, damage caused to so's health	
	[kilogram]		[kilogram]		[kilogram]		[kilogram]
	TS 1		TS 1		TS 1		TS 1
Truck	0.69	Truck	0.83	Truck	0.25	Truck	1.40
Sum:	0.69	Sum:	0.83	Sum:	0.25	Sum:	1.40
© EcoTransIT.org		© EcoTransIT.org		© EcoTransIT.org		© EcoTransIT.org	
Particulate matter (WTW) combustion related		Nitrogen oxides (WTW) Acidification, overfertilisation, smog		Particulate matter (WTW) combustion related		Nitrogen oxides (WTW) Acidification, overfertilisation, smog	
	[kilogram]		[kilogram]		[kilogram]		[kilogram]
	TS 1		TS 1		TS 1		TS 1
Truck	0.049	Truck	1.69	Truck	0.11	Truck	1.32
Sum:	0.049	Sum:	1.69	Sum:	0.11	Sum:	1.32
© EcoTransIT.org		© EcoTransIT.org		© EcoTransIT.org		© EcoTransIT.org	

Values of Air pollutants emissions related to LNG road transport to supply La Spezia from Barcelona using diesel (right) or LNG (left) as truck fuel (one way).

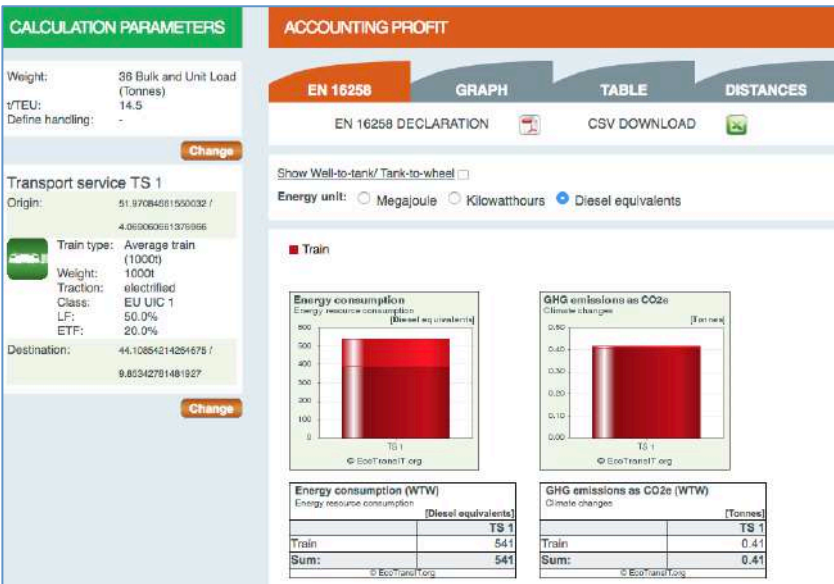
A3 - Energy consumption and GHGs related to rail transport to supply La Spezia with LNG from existing suitable terminals.

Zeebrugge – La Spezia



Energy consumption and GHGs related to LNG transport by rail to supply La Spezia from Zeebrugge (single trip of an average 1000t train).

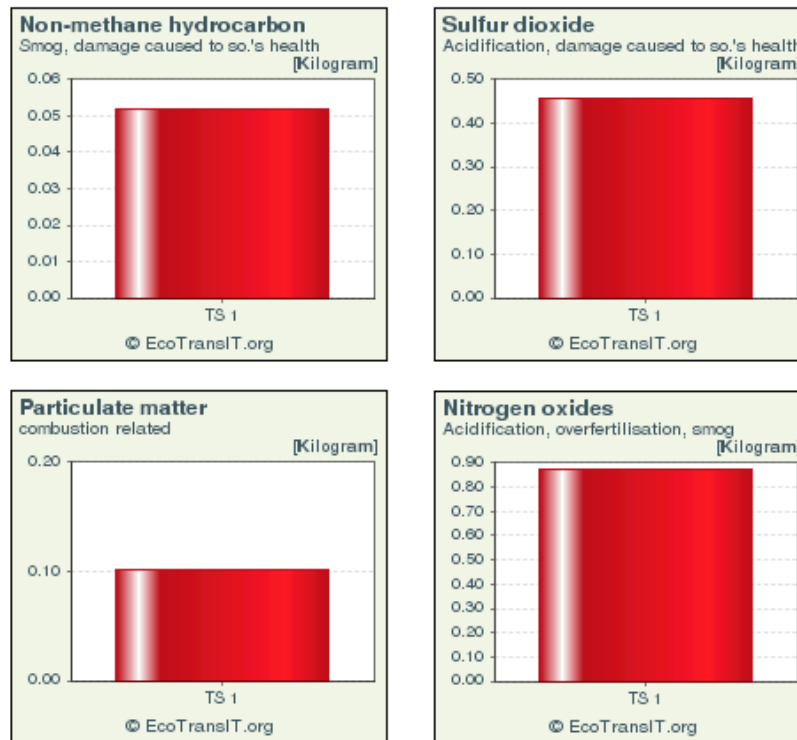
Rotterdam – La Spezia



Energy consumption and GHGs related to LNG transport by rail to supply La Spezia from Rotterdam (single trip of an average 1000t train).

A4 - Air pollutants emissions related to rail transport to supply La Spezia with LNG from existing suitable terminals.

Zeebrugge – La Spezia



Charts of Air pollutants emissions related to LNG rail transport to supply La Spezia from Zeebrugge.

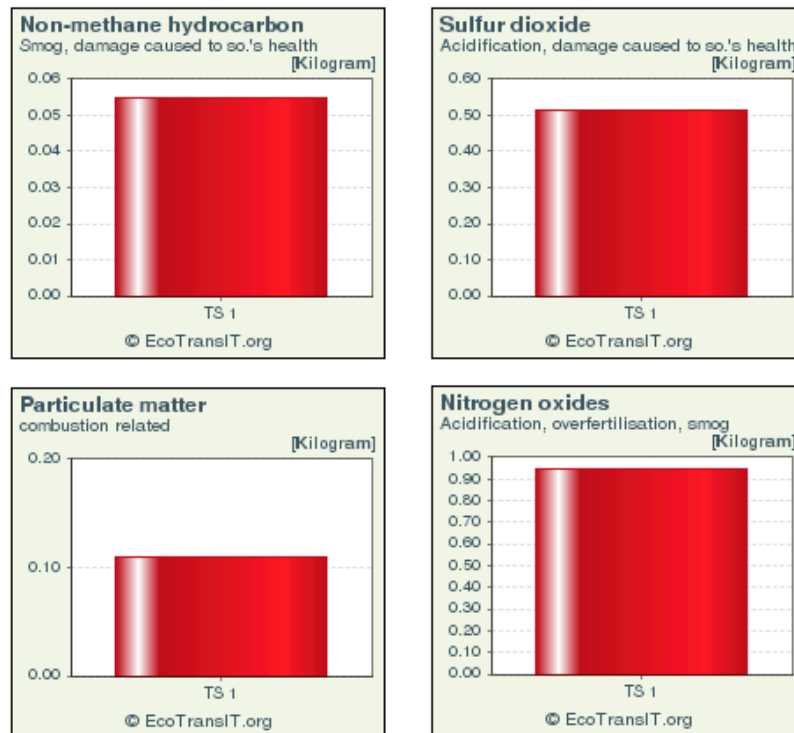
Non-methane hydrocarbon (WTW)	
Smog, damage caused to so.'s health	
	[kilogram]
	TS 1
Train	0.052
Sum:	0.052
© EcoTransIT.org	

Sulfur dioxide (WTW)	
Acidification, damage caused to so.'s health	
	[kilogram]
	TS 1
Train	0.46
Sum:	0.46
© EcoTransIT.org	

Particulate matter (WTW)	
combustion related	
	[kilogram]
	TS 1
Train	0.10
Sum:	0.10
© EcoTransIT.org	

Nitrogen oxides (WTW)	
Acidification, overfertilisation, smog	
	[kilogram]
	TS 1
Train	0.87
Sum:	0.87
© EcoTransIT.org	

Values of Air pollutants emissions related to LNG rail transport to supply La Spezia from Zeebrugge.



Charts of Air pollutants emissions related to LNG rail transport to supply La Spezia from Rotterdam.

Non-methane hydrocarbon (WTW) Smog, damage caused to so.'s health [kilogram]	
	TS 1
Train	0.055
Sum:	0.055
© EcoTransIT.org	

Sulfur dioxide (WTW) Acidification, damage caused to so.'s health [kilogram]	
	TS 1
Train	0.51
Sum:	0.51
© EcoTransIT.org	

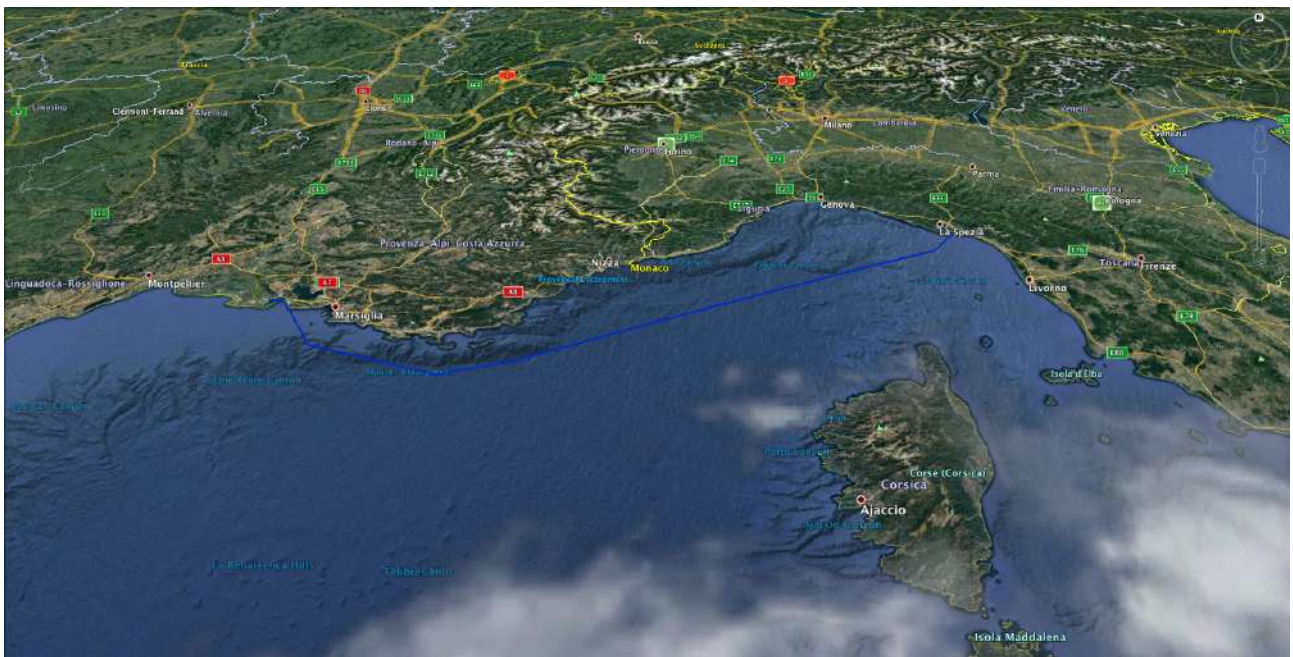
Particulate matter (WTW) combustion related [kilogram]	
	TS 1
Train	0.11
Sum:	0.11
© EcoTransIT.org	

Nitrogen oxides (WTW) Acidification, overfertilisation, smog [kilogram]	
	TS 1
Train	0.94
Sum:	0.94
© EcoTransIT.org	

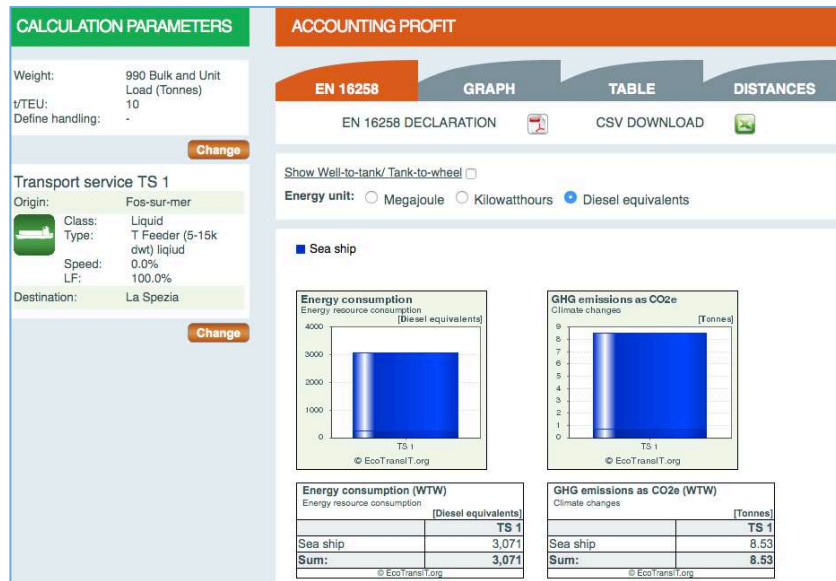
Values of Air pollutants emissions related to LNG rail transport to supply La Spezia from Rotterdam.

A5 - Energy consumption and GHGs related to waterborne transport to supply La Spezia with LNG from existing suitable terminals via 2200 m3 or 7500 m3 feeder ships.

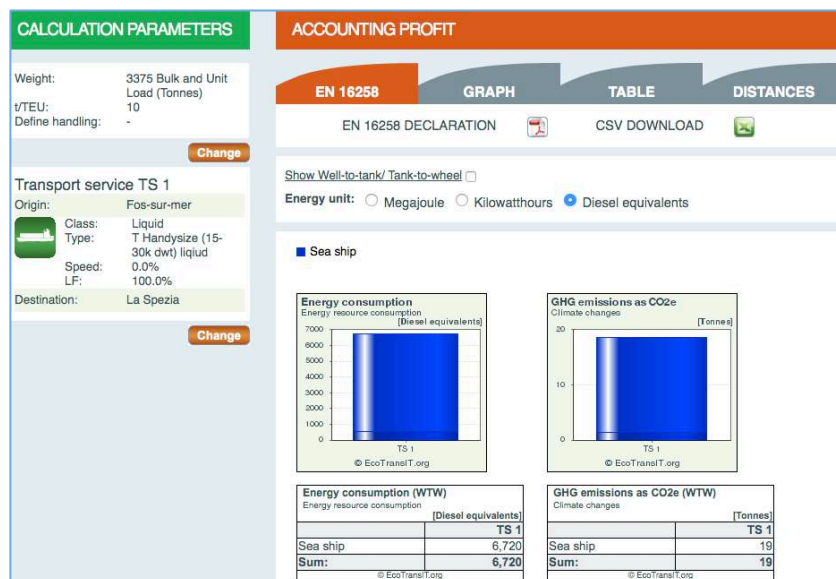
Marseille (Fos-sur-Mer) – La Spezia



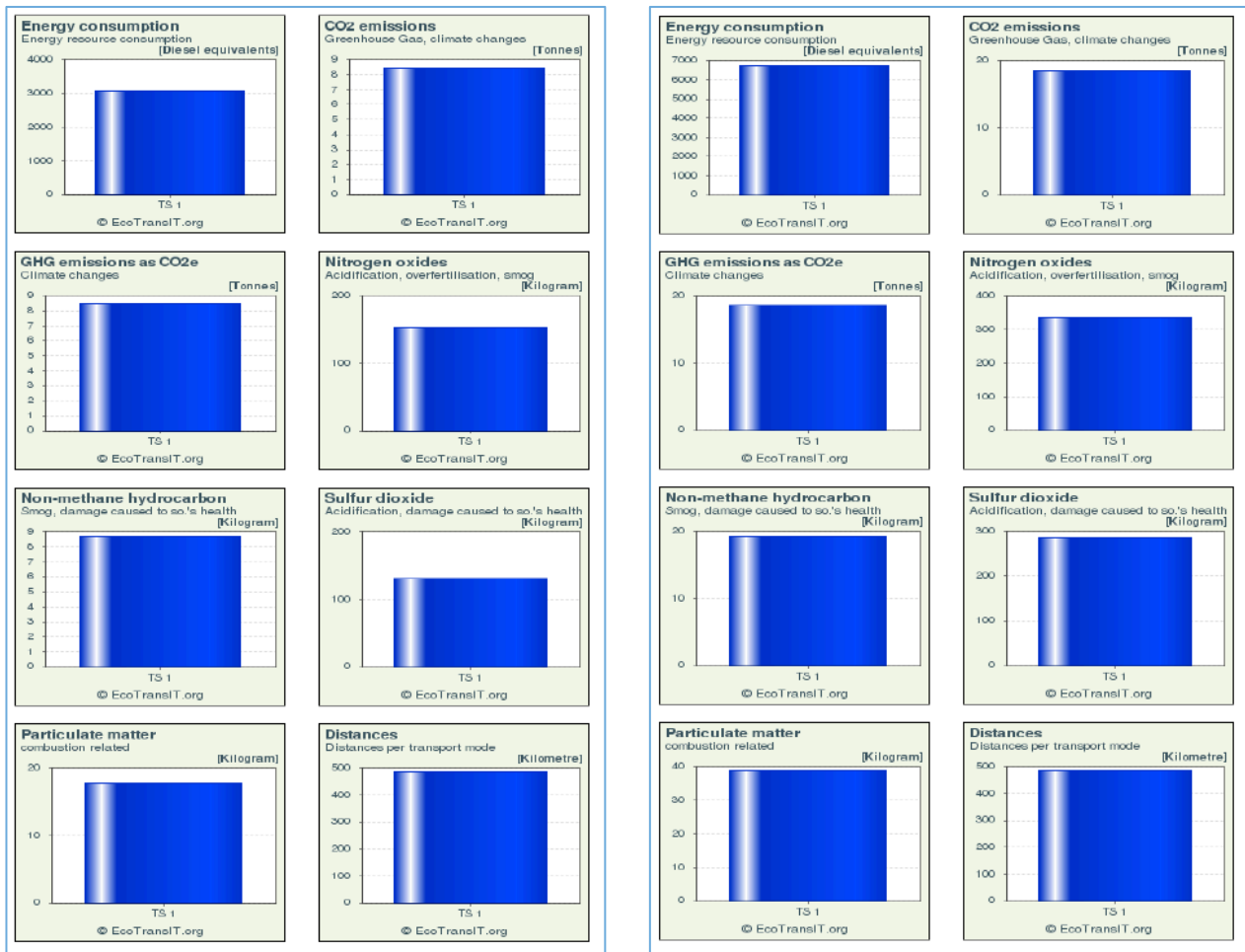
Marseille Fos-sur-Mer - La Spezia route. Source: EcoTransit via GoogleEarth.



Calculation parameters related related to LNG transport by ship to supply La Spezia from Marseille Fos-sur-Mer (single trip of a feeder ship for liquid cargo carrying 2200 m³ at 100% loading capacity) using HFO as fuel.



Calculation parameters related related to LNG transport by ship to supply La Spezia from Marseille Fos-sur-Mer (single trip of a carrier for liquid cargo carrying 7500 m³ at 100% loading capacity) using HFO as fuel.

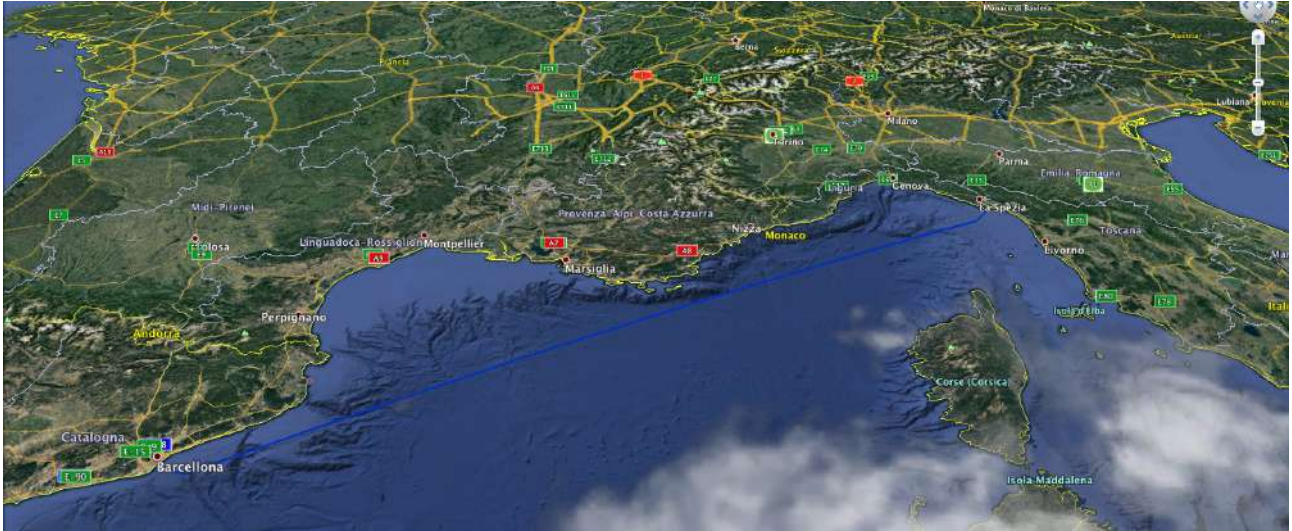


Charts comparison of energy consumption, GHGs, Air pollutants emissions related to LNG transport by ship to supply La Spezia from Marseille (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right) using HFO as fuel.

Energy consumption (WTW) Energy resource consumption [Diesel equivalents]	CO2 emissions (WTW) Greenhouse Gas, climate changes [Tonnes]	Energy consumption (WTW) Energy resource consumption [Diesel equivalents]	CO2 emissions (WTW) Greenhouse Gas, climate changes [Tonnes]
TS 1	TS 1	TS 1	TS 1
Sea ship 3,071	Sea ship 8.43	Sea ship 6,720	Sea ship 18
Sum: 3,071	Sum: 8.43	Sum: 6,720	Sum: 18
© EcoTrans1.org	© EcoTrans1.org	© EcoTrans1.org	© EcoTrans1.org
GHG emissions as CO2e (WTW) Climate changes [Tonnes]	Nitrogen oxides (WTW) Acidification, overfertilisation, smog [kilogram]	GHG emissions as CO2e (WTW) Climate changes [Tonnes]	Nitrogen oxides (WTW) Acidification, overfertilisation, smog [kilogram]
TS 1	TS 1	TS 1	TS 1
Sea ship 8.53	Sea ship 153	Sea ship 19	Sea ship 336
Sum: 8.53	Sum: 153	Sum: 19	Sum: 336
© EcoTrans1.org	© EcoTrans1.org	© EcoTrans1.org	© EcoTrans1.org
Non-methane hydrocarbon (WTW) Smog, damage caused to so's health [kilogram]	Sulfur dioxide (WTW) Acidification, damage caused to so's health [kilogram]	Non-methane hydrocarbon (WTW) Smog, damage caused to so's health [kilogram]	Sulfur dioxide (WTW) Acidification, damage caused to so's health [kilogram]
TS 1	TS 1	TS 1	TS 1
Sea ship 8.73	Sea ship 131	Sea ship 19	Sea ship 288
Sum: 8.73	Sum: 131	Sum: 19	Sum: 288
© EcoTrans1.org	© EcoTrans1.org	© EcoTrans1.org	© EcoTrans1.org
Particulate matter (WTW) combustion related [kilogram]	Distances (WTW) Distances per transport mode [km]	Particulate matter (WTW) combustion related [kilogram]	Distances (WTW) Distances per transport mode [km]
TS 1	TS 1	TS 1	TS 1
Sea ship 18	Sea ship 485	Sea ship 39	Sea ship 485
Sum: 18	Sum: 485	Sum: 39	Sum: 485
© EcoTrans1.org	© EcoTrans1.org	© EcoTrans1.org	© EcoTrans1.org

Values comparison of energy consumption, GHGs, Air pollutants emissions related to LNG transport by ship to supply La Spezia from Marseille (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right) using HFO as fuel.

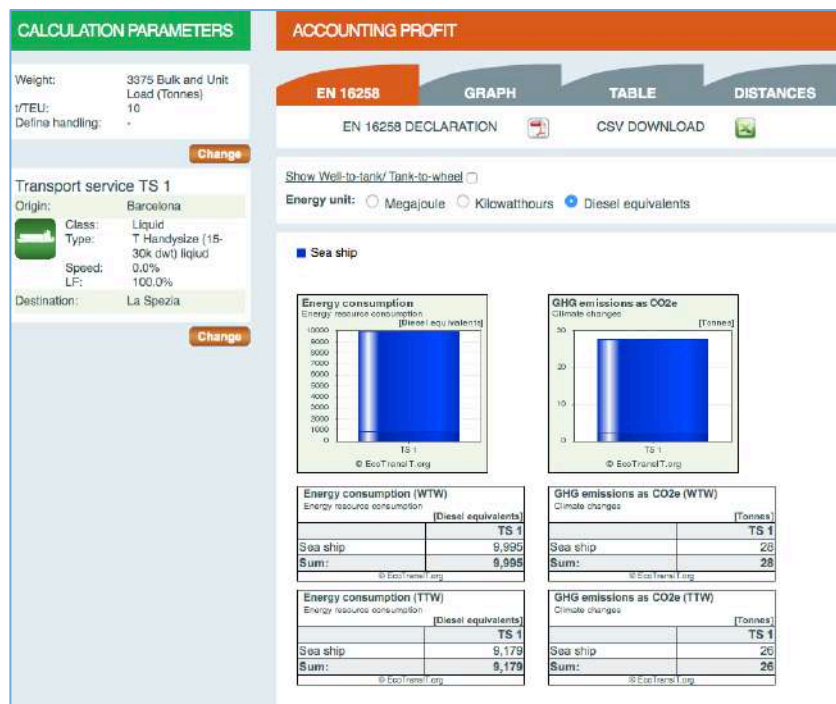
Barcelona – La Spezia



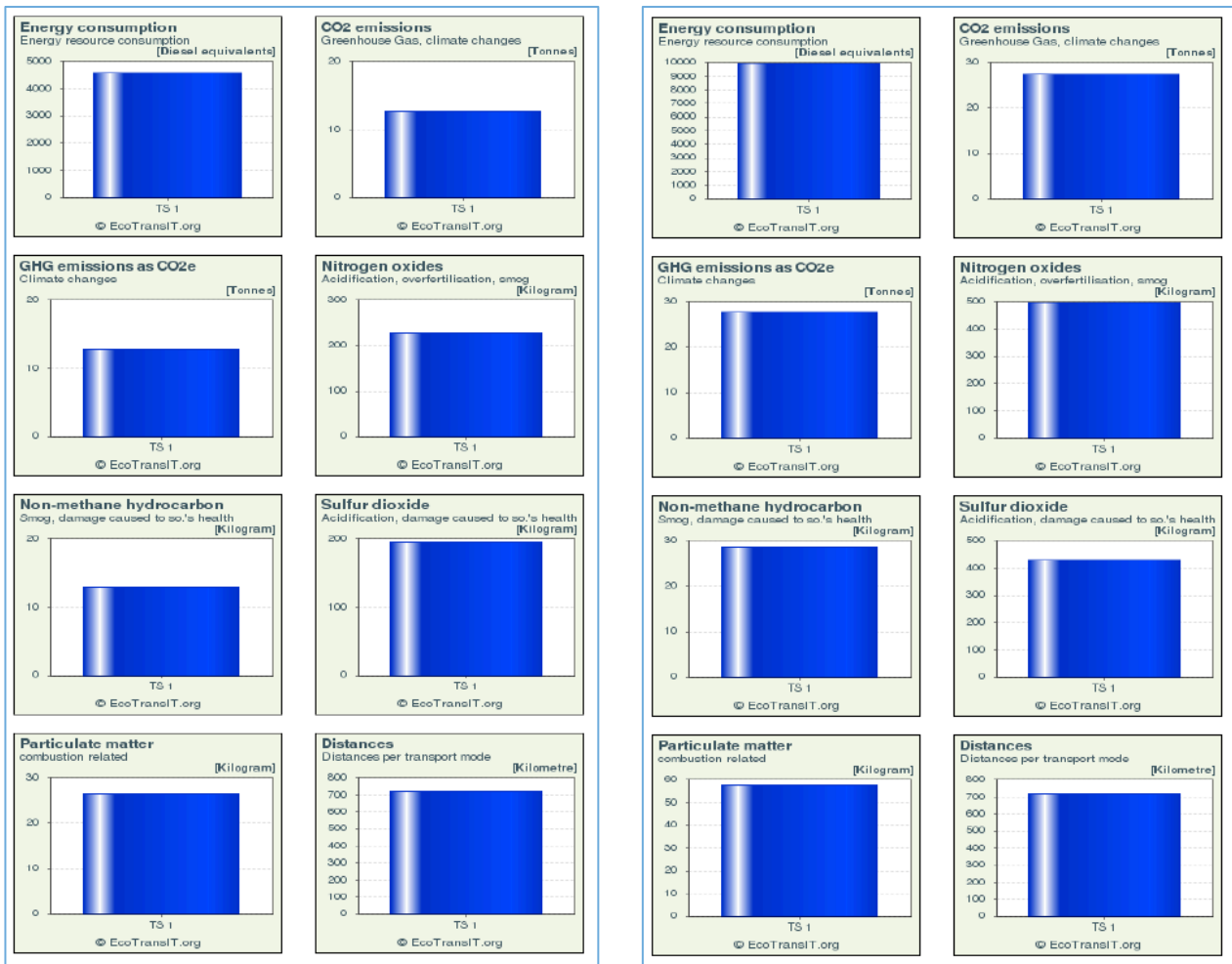
Barcelona-La Spezia route. Source: EcoTransit via GoogleEarth.



Calculation parameters related related to LNG transport by ship to supply La Spezia from Barcelona (single trip of a feeder ship for liquid cargo carrying 2200 m³ at 100% loading capacity) using HFO as fuel.



Calculation parameters related related to LNG transport by ship to supply La Spezia from Barcelona (single trip of a carrier for liquid cargo carrying 7500 m³ at 100% loading capacity) using HFO as fuel.



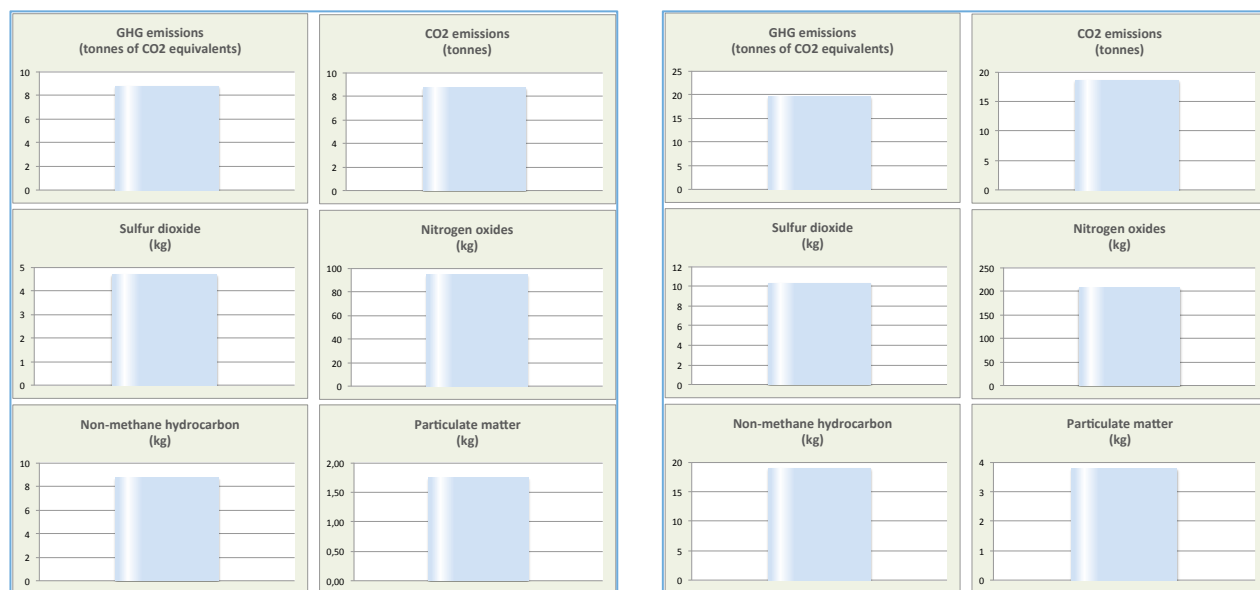
Charts comparison of energy consumption, GHGs, Air pollutants emissions related to LNG transport by ship to supply La Spezia from Barcelona (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right) using HFO as fuel.

Energy consumption (WTW) Energy resource consumption		CO2 emissions (WTW) Greenhouse Gas, climate changes		Energy consumption (WTW) Energy resource consumption		CO2 emissions (WTW) Greenhouse Gas, climate changes	
[Diesel equivalents]		[Tonnes]		[Diesel equivalents]		[Tonnes]	
	TS 1		TS 1		TS 1		TS 1
Sea ship	4,567	Sea ship	13	Sea ship	9,995	Sea ship	27
Sum:	4,567	Sum:	13	Sum:	9,995	Sum:	27
© EcoTransIT.org		© EcoTransIT.org		© EcoTransIT.org		© EcoTransIT.org	
GHG emissions as CO2e (WTW) Climate changes		Nitrogen oxides (WTW) Acidification, overfertilisation, smog		GHG emissions as CO2e (WTW) Climate changes		Nitrogen oxides (WTW) Acidification, overfertilisation, smog	
[Tonnes]		[kilogram]		[Tonnes]		[kilogram]	
	TS 1		TS 1		TS 1		TS 1
Sea ship	13	Sea ship	228	Sea ship	28	Sea ship	499
Sum:	13	Sum:	228	Sum:	28	Sum:	499
© EcoTransIT.org		© EcoTransIT.org		© EcoTransIT.org		© EcoTransIT.org	
Non-methane hydrocarbon (WTW) Smog, damage caused to so's health		Sulfur dioxide (WTW) Acidification, damage caused to so's health		Non-methane hydrocarbon (WTW) Smog, damage caused to so's health		Sulfur dioxide (WTW) Acidification, damage caused to so's health	
[kilogram]		[kilogram]		[kilogram]		[kilogram]	
	TS 1		TS 1		TS 1		TS 1
Sea ship	13	Sea ship	195	Sea ship	29	Sea ship	428
Sum:	13	Sum:	195	Sum:	29	Sum:	428
© EcoTransIT.org		© EcoTransIT.org		© EcoTransIT.org		© EcoTransIT.org	
Particulate matter (WTW) combustion related		Distances (WTW) Distances per transport mode		Particulate matter (WTW) combustion related		Distances (WTW) Distances per transport mode	
[kilogram]		[km]		[kilogram]		[km]	
	TS 1		TS 1		TS 1		TS 1
Sea ship	26	Sea ship	721	Sea ship	58	Sea ship	721
Sum:	26	Sum:	721	Sum:	58	Sum:	721
© EcoTransIT.org		© EcoTransIT.org		© EcoTransIT.org		© EcoTransIT.org	

Values comparison of energy consumption, GHGs, Air pollutants emissions related to LNG transport by ship to supply La Spezia from Barcelona (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right) using HFO as fuel.

A6 – Waterborne transport 2020 scenario. GHGs and air pollutants emissions related to waterborne transport to supply La Spezia with LNG from existing suitable terminals via 2200 m³ or 7500 m³ feeder ships (LNG/conventional fuel comparison).

Marseille (Fos-sur-Mer) – La Spezia

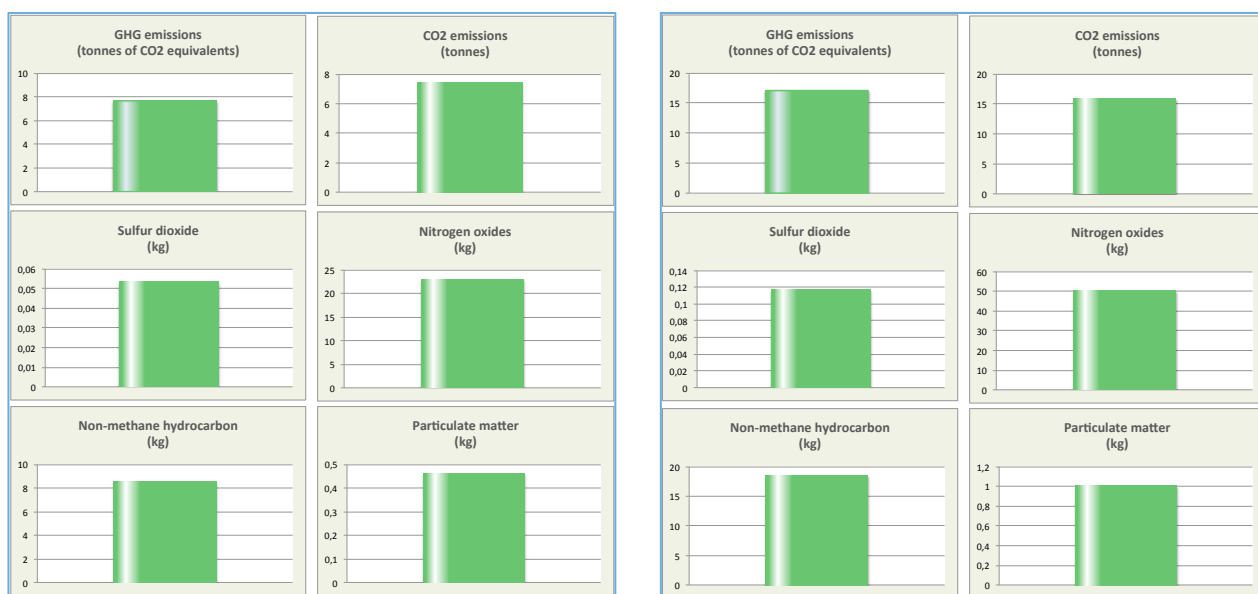


Charts comparison of energy consumption, GHGs and air pollutants emissions related to LNG transport by ship to supply La Spezia from Marseille (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right) using MDO as fuel. Data derived from HFO's values, using MDO's main engine emission factors (values in g/g fuel) of IMO's third GHG Study.

CO ₂ emissions (tonnes)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
8,70	8,77
Non-methane hydrocarbon (kg)	Sulfur dioxide (kg)
8,73	4,70
Nitrogen oxides (kg)	Particulate matter (kg)
94,40	1,75

CO ₂ emissions (tonnes)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
18,58	19,54
Non-methane hydrocarbon (kg)	Sulfur dioxide (kg)
19,00	10,32
Nitrogen oxides (kg)	Particulate matter (kg)
207,32	3,78

Values comparison of energy consumption, GHGs, Air pollutants emissions related to LNG transport by ship to supply La Spezia from Marseille (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right), using HFO as fuel. Data derived from HFO's values, using MDO's main engine emission factors (values in g/g fuel) of IMO's third GHG Study.



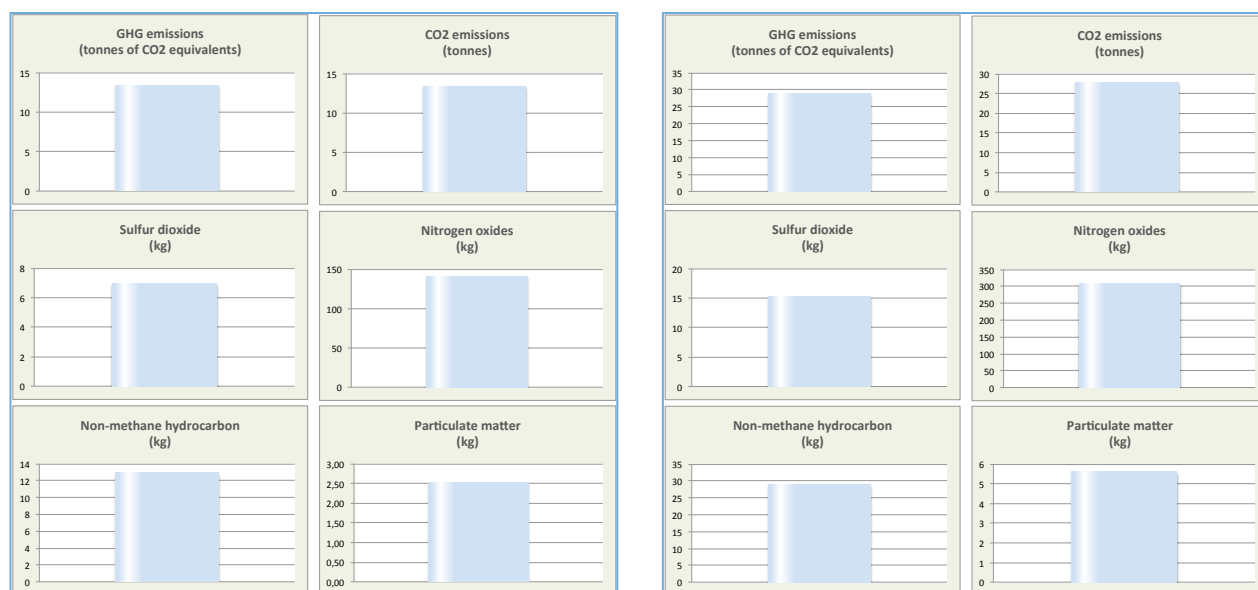
Charts comparison of energy consumption, GHGs and air pollutants emissions related to LNG transport by ship to supply La Spezia from Marseille (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right) using LNG as fuel. Data derived from HFO's values, using LNG's main engine emission factors (values in g/g fuel) of IMO's third GHG Study.

CO ₂ emissions (tonnes)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
7,44	7,67
Non-methane hydrocarbon (kg)	Sulfur dioxide (kg)
8,53	0,05
Nitrogen oxides (kg)	Particulate matter (kg)
23,00	0,46

CO ₂ emissions (tonnes)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
15,90	17,07
Non-methane hydrocarbon (kg)	Sulfur dioxide (kg)
18,57	0,12
Nitrogen oxides (kg)	Particulate matter (kg)
50,51	1,00

Values comparison of energy consumption, GHGs, Air pollutants emissions related to LNG transport by ship to supply La Spezia from Marseille (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right), using LNG as fuel. Data derived from HFO's values, using LNG's main engine emission factors (values in g/g fuel) of IMO's third GHG Study.

Barcelona – La Spezia

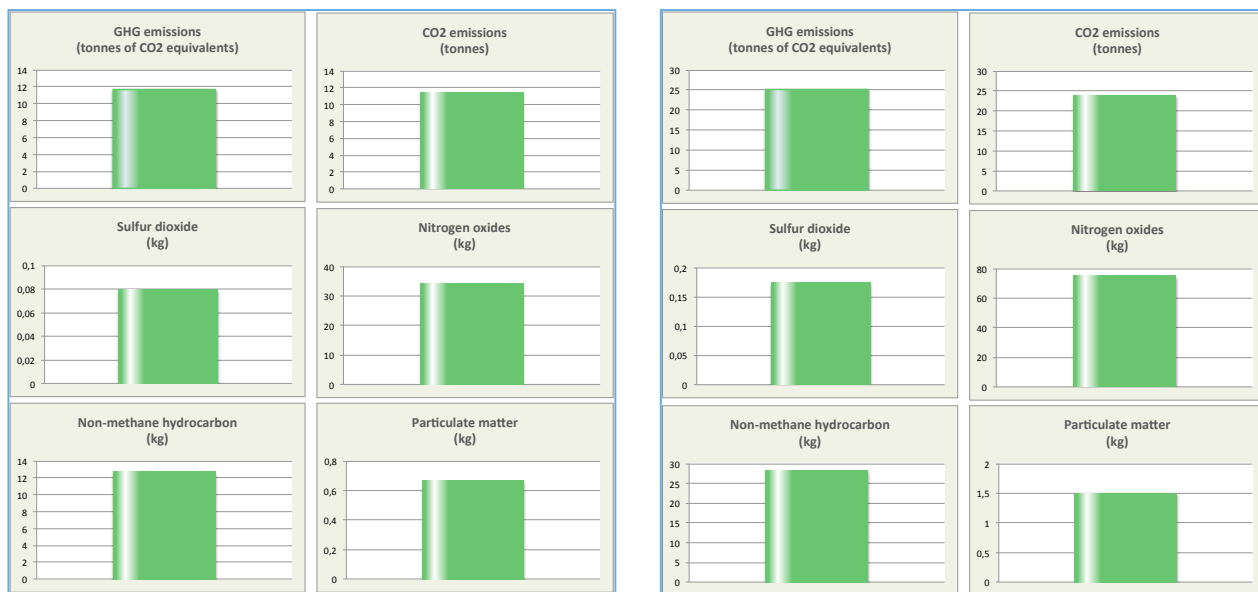


Charts comparison of energy consumption, GHGs and air pollutants emissions related to LNG transport by ship to supply La Spezia from Barcelona (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right) using MDO as fuel. Data derived from HFO's values, using MDO's main engine emission factors (values in g/g fuel) of IMO's third GHG Study.

CO ₂ emissions (tonnes)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
13,42	13,37
Non-methane hydrocarbon (kg)	Sulfur dioxide (kg)
13,00	6,99
Nitrogen oxides (kg)	Particulate matter (kg)
140,68	2,52

CO ₂ emissions (tonnes)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
27,87	28,80
Non-methane hydrocarbon (kg)	Sulfur dioxide (kg)
29,00	15,34
Nitrogen oxides (kg)	Particulate matter (kg)
307,89	5,63

Values comparison of energy consumption, GHGs, Air pollutants emissions related to LNG transport by ship to supply La Spezia from Barcelona (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right), using HFO as fuel. Data derived from HFO's values, using MDO's main engine emission factors (values in g/g fuel) of IMO's third GHG Study.

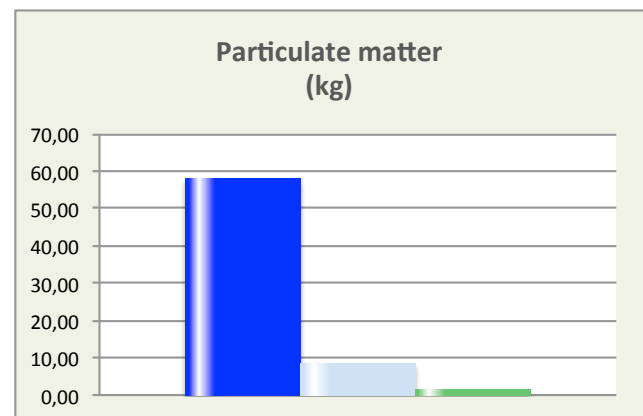
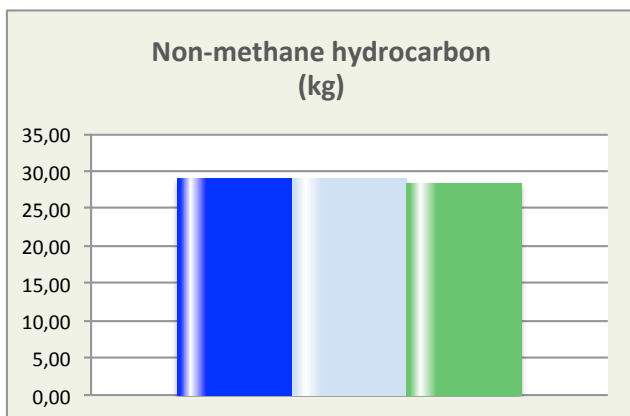
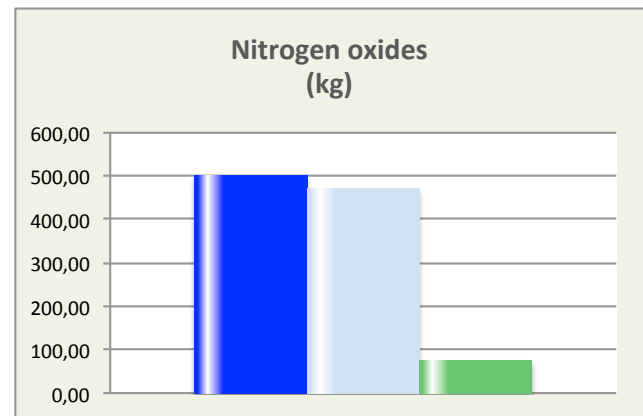
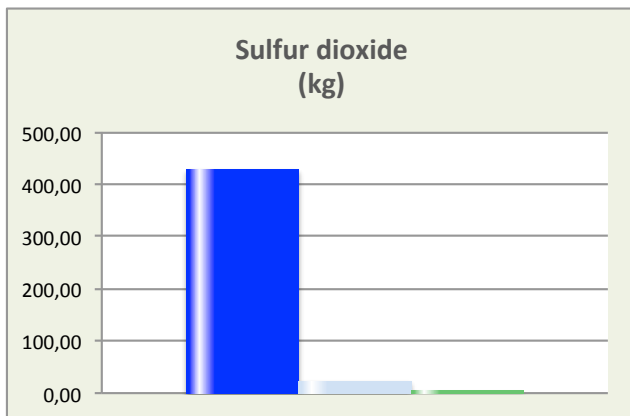
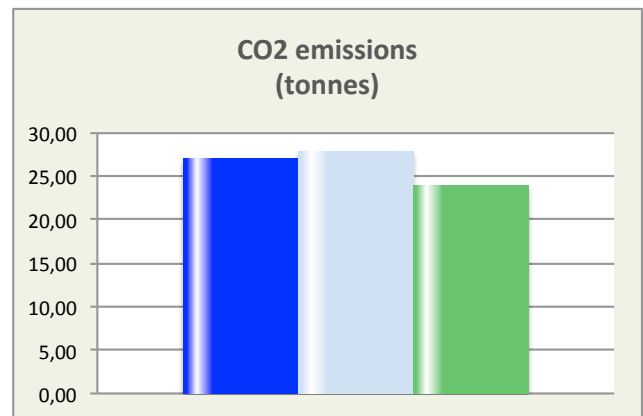
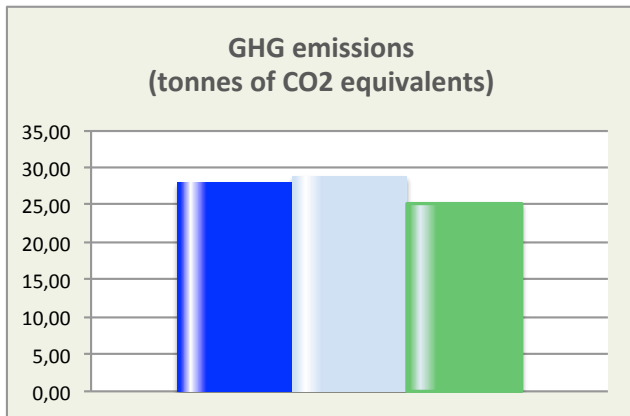


Charts comparison of energy consumption, GHGs and air pollutants emissions related to LNG transport by ship to supply La Spezia from Barcelona (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right) using LNG as fuel. Data derived from LNG's values, using MDO's main engine emission factors (values in g/g fuel) of IMO's third GHG Study.

CO ₂ emissions (tonnes)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
11,48	11,68
Non-methane hydrocarbon (kg)	Sulfur dioxide (kg)
12,70	0,08
Nitrogen oxides (kg)	Particulate matter (kg)
34,27	0,67

CO ₂ emissions (tonnes)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
23,84	25,16
Non-methane hydrocarbon (kg)	Sulfur dioxide (kg)
28,34	0,17
Nitrogen oxides (kg)	Particulate matter (kg)
75,01	1,49

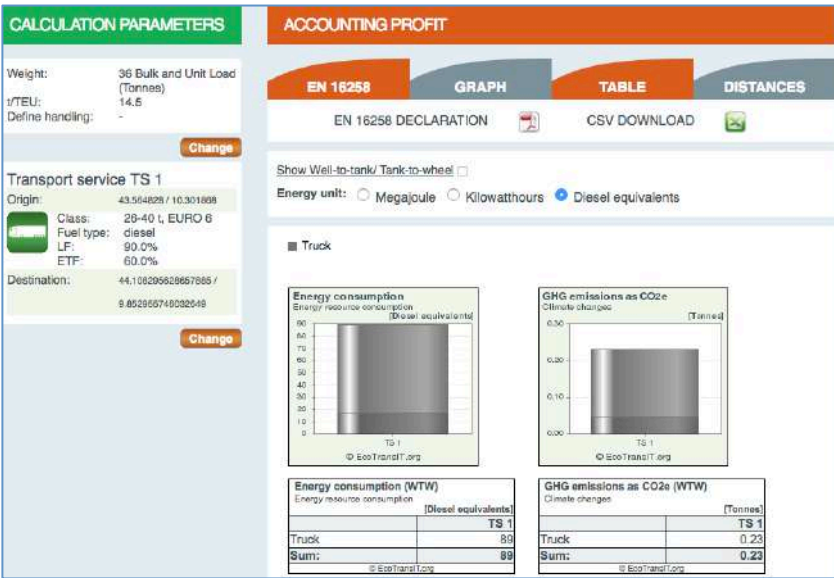
Values comparison of energy consumption, GHGs, Air pollutants emissions related to LNG transport by ship to supply La Spezia from Barcelona (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right), using LNG as fuel. Data derived from HFO's values, using LNG's main engine emission factors (values in g/g fuel) of IMO's third GHG Study.



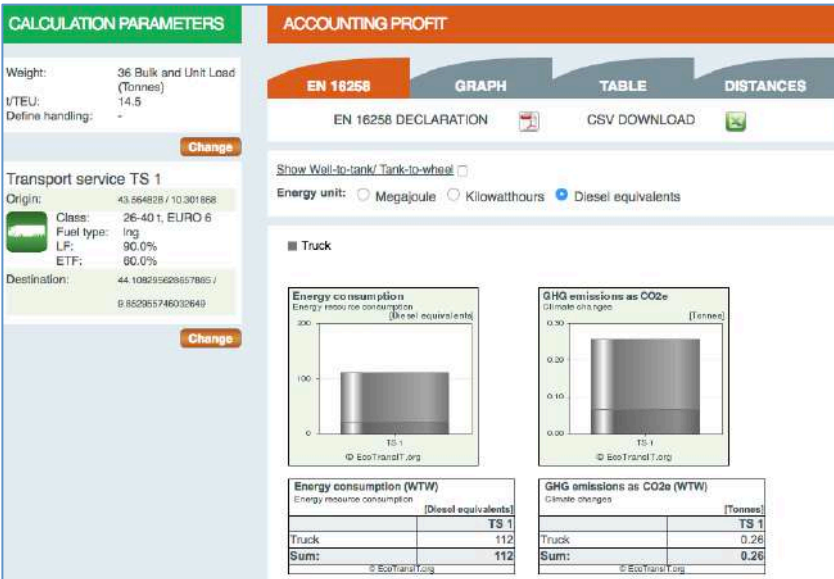
Appendix B – EcoTransit LNG transport simulation results on single trips from suitable planned LNG terminals.

B1 - Energy consumption and GHGs related to LNG road transport to supply La Spezia from suitable planned terminals using diesel or LNG as a truck fuel.

Livorno – La Spezia

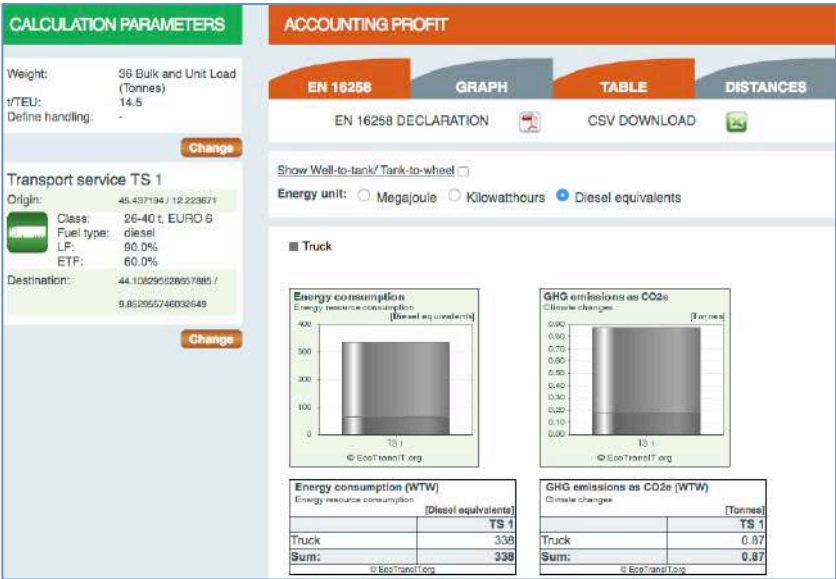


Energy consumption and GHGs related to LNG road transport to supply La Spezia from planned terminal in Livorno using diesel as truck fuel (one way).

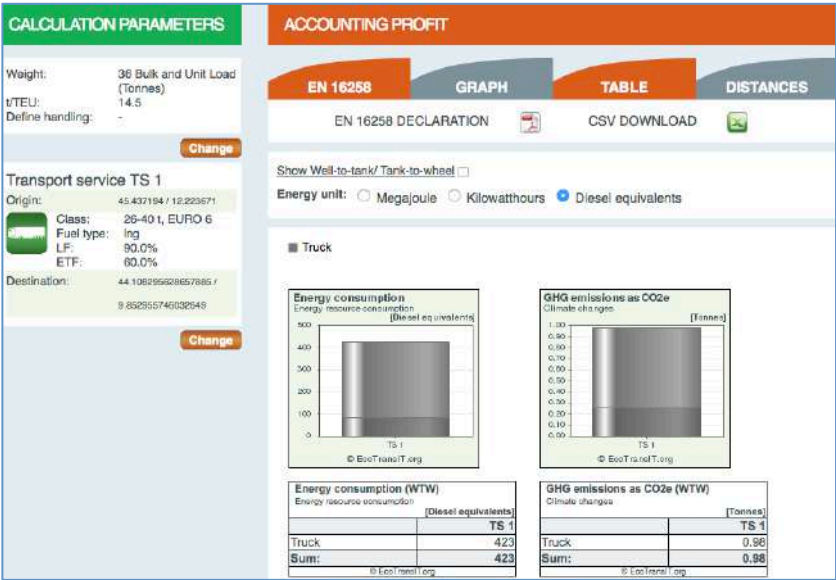


Energy consumption and GHGs related to LNG road transport to supply La Spezia from planned terminal in Livorno using LNG as truck fuel (one way).

Venezia – La Spezia

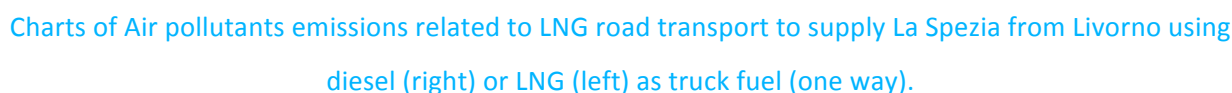


Energy consumption and GHGs related to LNG road transport to supply La Spezia from planned terminal in Vanezia using diesel as truck fuel (one way).

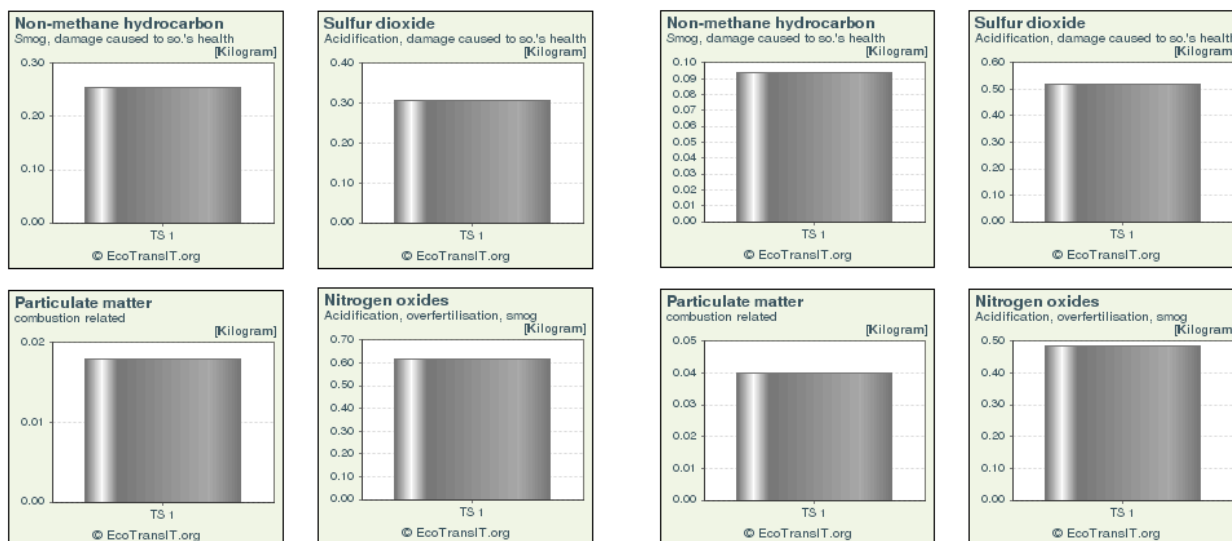


Energy consumption and GHGs related to LNG road transport to supply La Spezia from planned terminal in Vanezia using LNG as truck fuel (one way).

Livorno – La Spezia



Values of Air pollutants emissions related to LNG road transport to supply La Spezia from Livorno using diesel (right) or LNG (left) as truck fuel (one way).



Charts of Air pollutants emissions related to LNG road transport to supply La Spezia from Venezia using diesel (right) or LNG (left) as truck fuel (one way).

Non-methane hydrocarbon (WTW)

Smog, damage caused to so.'s health

Truck

Sum:

0.26

0.26

© EcoTransIT.org

Sulfur dioxide (WTW)

Acidification, damage caused to so.'s health

Truck

Sum:

0.31

0.31

© EcoTransIT.org

Non-methane hydrocarbon (WTW)

Smog, damage caused to so.'s health

Truck

Sum:

0.094

0.094

© EcoTransIT.org

Sulfur dioxide (WTW)

Acidification, damage caused to so.'s health

Truck

Sum:

0.52

0.52

© EcoTransIT.org

Particulate matter (WTW)

combustion related

Truck

Sum:

0.018

0.018

© EcoTransIT.org

Nitrogen oxides (WTW)

Acidification, overfertilisation, smog

Truck

Sum:

0.62

0.62

© EcoTransIT.org

Particulate matter (WTW)

combustion related

Truck

Sum:

0.040

0.040

© EcoTransIT.org

Nitrogen oxides (WTW)

Acidification, overfertilisation, smog

Truck

Sum:

0.49

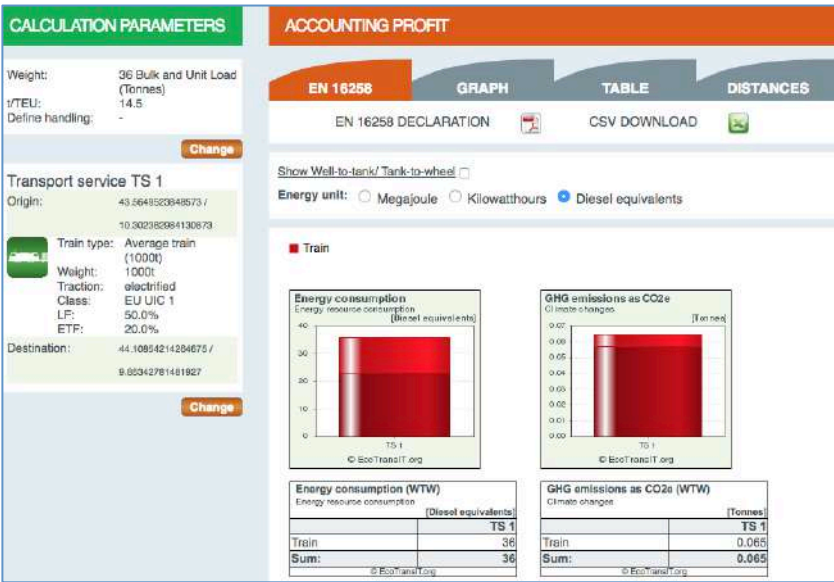
0.49

© EcoTransIT.org

Values of Air pollutants emissions related to LNG road transport to supply La Spezia from Venezia using diesel (right) or LNG (left) as truck fuel (one way).

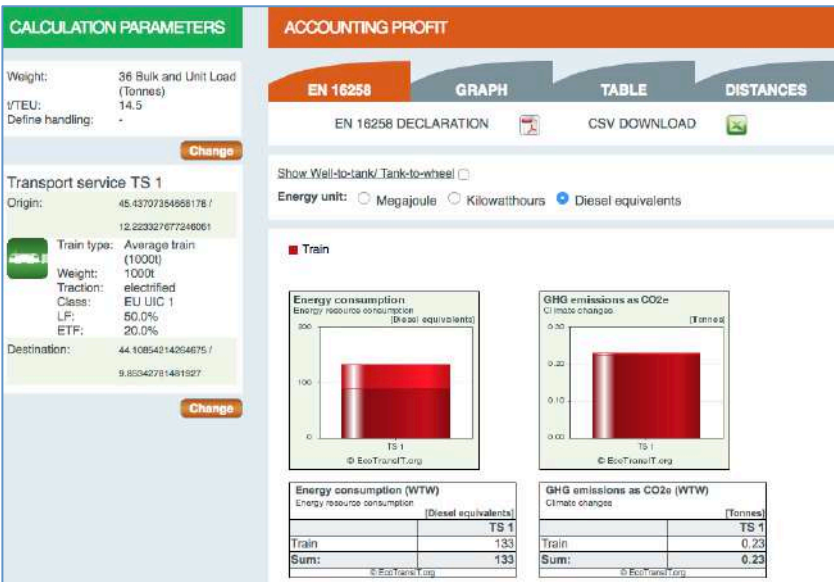
B3 - Energy consumption and GHGs related to rail transport to supply La Spezia with LNG ISO-containers from planned suitable terminals.

Livorno – La Spezia



Energy consumption and GHGs related to LNG transport by rail to supply La Spezia from Livorno (single trip of an average 1000t train).

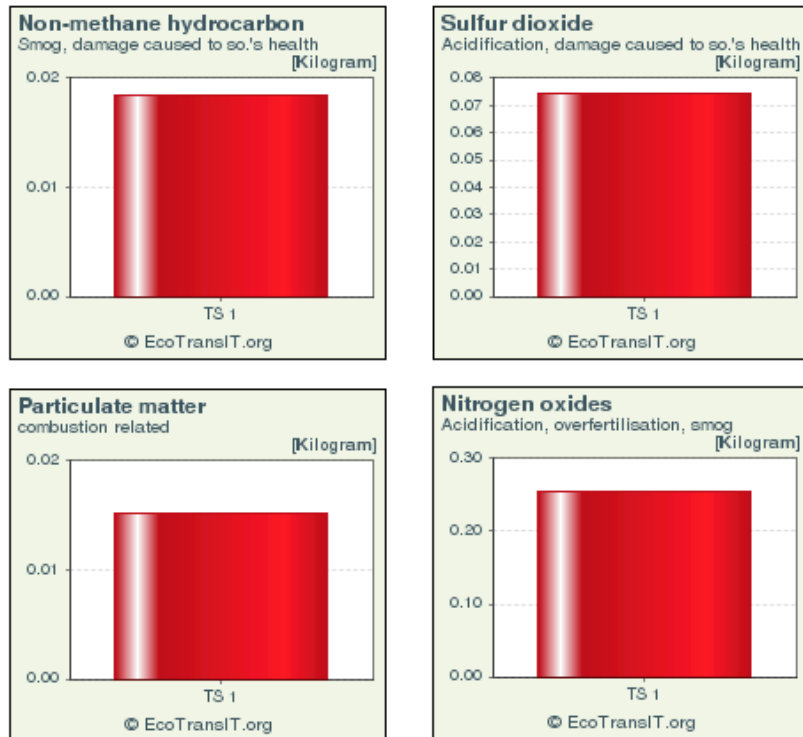
Venezia – La Spezia



Energy consumption and GHGs related to LNG transport by rail to supply La Spezia from Venezia (single trip of an average 1000t train).

B4 - Air pollutants emissions related to rail transport to supply La Spezia with LNG ISO-containers from planned suitable terminals.

Livorno – La Spezia



Charts of Air pollutants emissions related to LNG rail transport to supply La Spezia from Livorno.

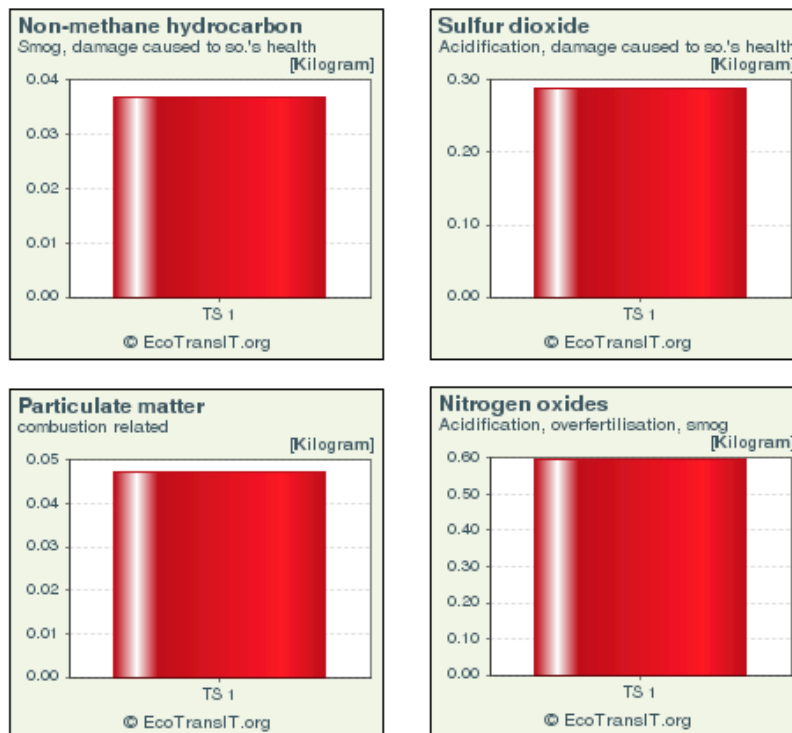
Non-methane hydrocarbon (WTW) Smog, damage caused to so.'s health [kilogram]	
	TS 1
Train	0.019
Sum:	0.019
© EcoTransIT.org	

Sulfur dioxide (WTW) Acidification, damage caused to so.'s health [kilogram]	
	TS 1
Train	0.074
Sum:	0.074
© EcoTransIT.org	

Particulate matter (WTW) combustion related [kilogram]	
	TS 1
Train	0.015
Sum:	0.015
© EcoTransIT.org	

Nitrogen oxides (WTW) Acidification, overfertilisation, smog [kilogram]	
	TS 1
Train	0.25
Sum:	0.25
© EcoTransIT.org	

Values of Air pollutants emissions related to LNG rail transport to supply La Spezia from Livorno.



Charts of Air pollutants emissions related to LNG rail transport to supply La Spezia from Venezia.

Non-methane hydrocarbon (WTW) Smog, damage caused to so.'s health [kilogram]	
	TS 1
Train	0.037
Sum:	0.037
© EcoTransIT.org	

Sulfur dioxide (WTW) Acidification, damage caused to so.'s health [kilogram]	
	TS 1
Train	0.29
Sum:	0.29
© EcoTransIT.org	

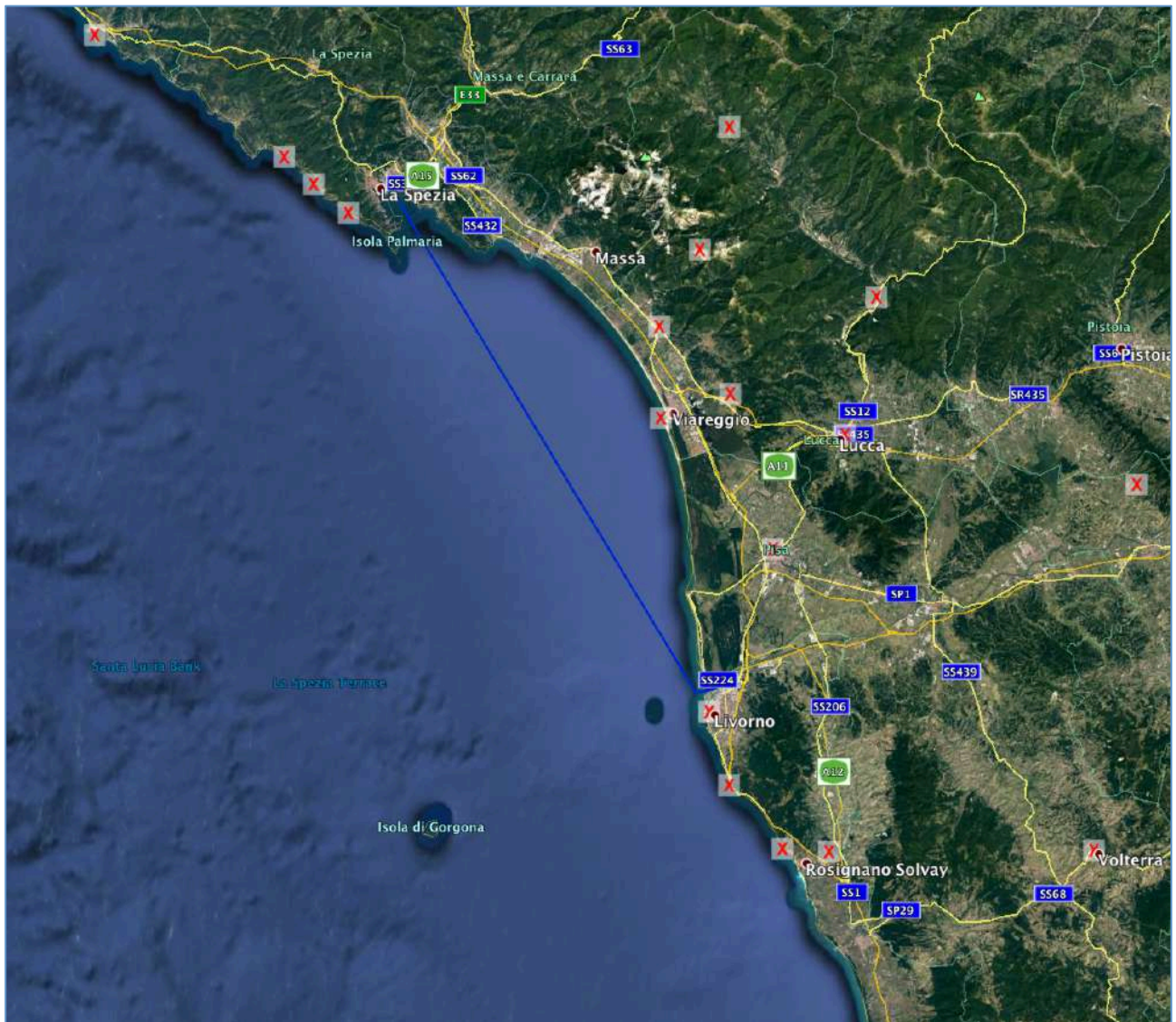
Particulate matter (WTW) combustion related [kilogram]	
	TS 1
Train	0.047
Sum:	0.047
© EcoTransIT.org	

Nitrogen oxides (WTW) Acidification, overfertilisation, smog [kilogram]	
	TS 1
Train	0.60
Sum:	0.60
© EcoTransIT.org	

Values of Air pollutants emissions related to LNG rail transport to supply La Spezia from Venezia.

B5 - Energy consumption, GHGs, Air pollutants emissions related to waterborne transport to supply La Spezia with LNG from planned suitable terminals via 2200 m3 or 7500 m3 feeder ships.

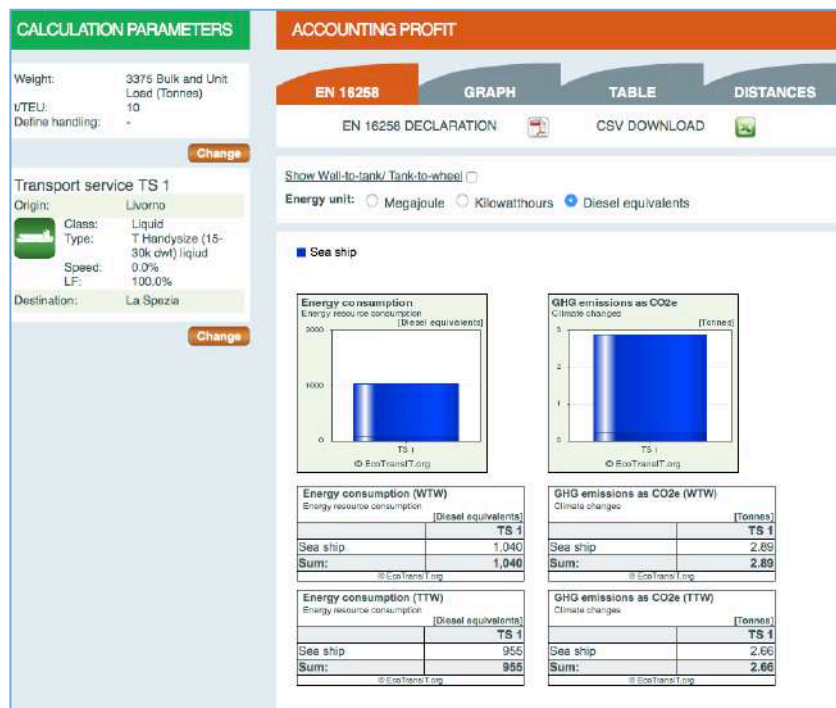
Livorno – La Spezia



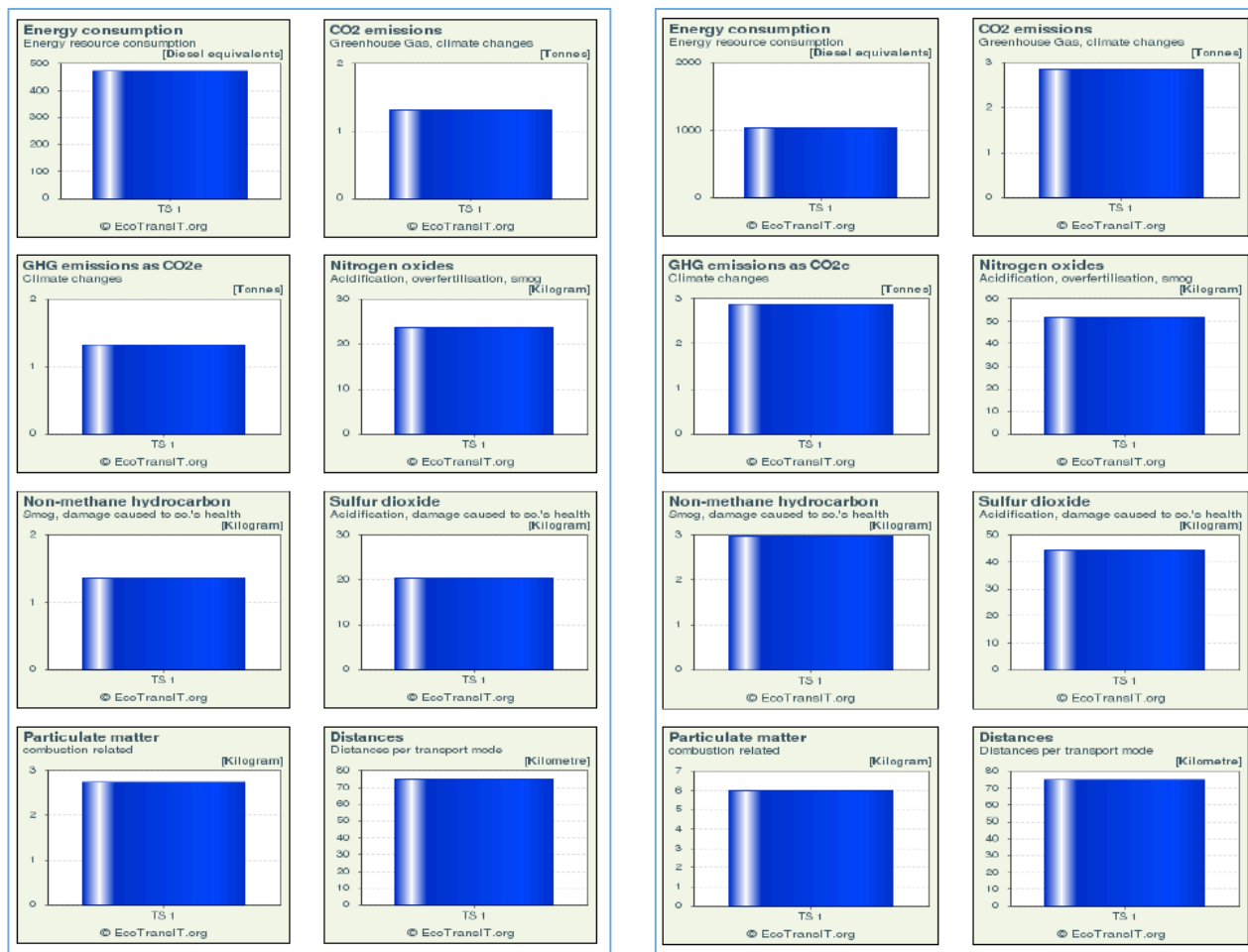
Livorno - La Spezia route. Source: EcoTransit via GoogleEarth.



Calculation parameters related to LNG transport by ship to supply La Spezia from Livorno (single trip of a feeder ship for liquid cargo carrying 2200 m³ at 100% loading capacity) using HFO as fuel.



Calculation parameters related to LNG transport by ship to supply La Spezia from Livorno (single trip of a large LNG bunkering ship for liquid cargo carrying 7500 m³ at 100% loading capacity) using HFO as fuel.



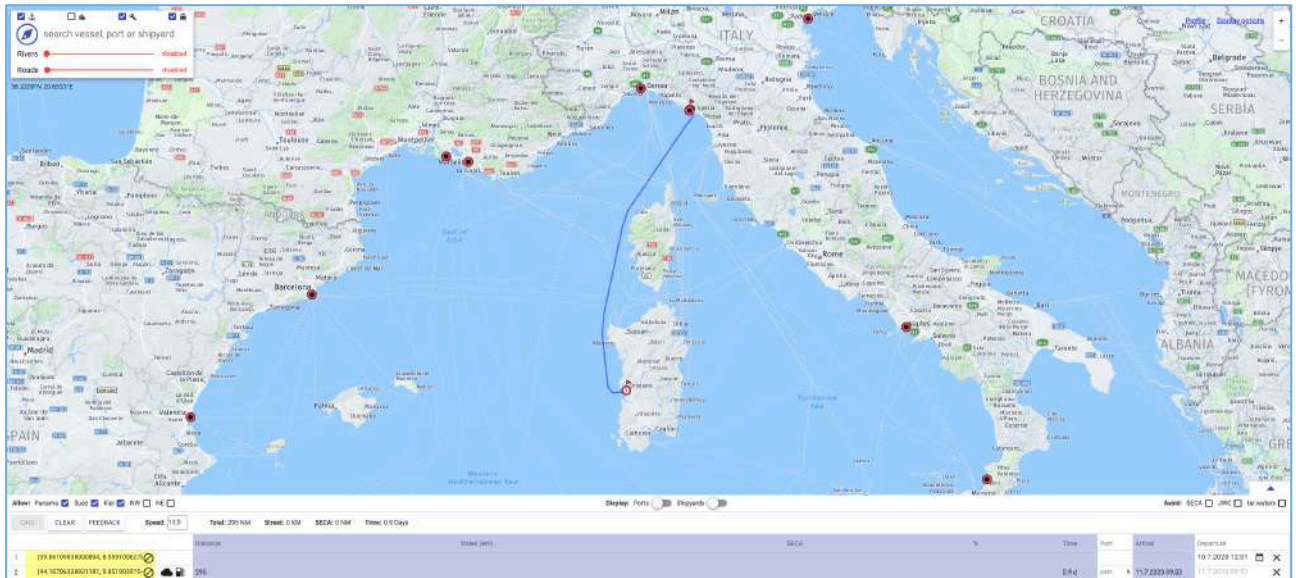
Charts comparison of energy consumption, GHGs, Air pollutants emissions related to LNG transport by ship to supply La Spezia from Livorno (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right) using HFO as fuel.

Energy consumption (WTW) Energy resource consumption [Diesel equivalents]	CO2 emissions (WTW) Greenhouse Gas, climate changes [Tonnes]												
<table> <tr><td></td><td>TS 1</td></tr> <tr><td>Sea ship</td><td>475</td></tr> <tr><td>Sum:</td><td>475</td></tr> </table>		TS 1	Sea ship	475	Sum:	475	<table> <tr><td></td><td>TS 1</td></tr> <tr><td>Sea ship</td><td>1.31</td></tr> <tr><td>Sum:</td><td>1.31</td></tr> </table>		TS 1	Sea ship	1.31	Sum:	1.31
	TS 1												
Sea ship	475												
Sum:	475												
	TS 1												
Sea ship	1.31												
Sum:	1.31												
GHG emissions as CO2e (WTW) Climate changes [Tonnes]	Nitrogen oxides (WTW) Acidification, overfertilisation, smog [kilogram]												
<table> <tr><td></td><td>TS 1</td></tr> <tr><td>Sea ship</td><td>1.32</td></tr> <tr><td>Sum:</td><td>1.32</td></tr> </table>		TS 1	Sea ship	1.32	Sum:	1.32	<table> <tr><td></td><td>TS 1</td></tr> <tr><td>Sea ship</td><td>24</td></tr> <tr><td>Sum:</td><td>24</td></tr> </table>		TS 1	Sea ship	24	Sum:	24
	TS 1												
Sea ship	1.32												
Sum:	1.32												
	TS 1												
Sea ship	24												
Sum:	24												
Non-methane hydrocarbon (WTW) Smog, damage caused to so's health [kilogram]	Sulfur dioxide (WTW) Acidification, damage caused to so's health [kilogram]												
<table> <tr><td></td><td>TS 1</td></tr> <tr><td>Sea ship</td><td>1.35</td></tr> <tr><td>Sum:</td><td>1.35</td></tr> </table>		TS 1	Sea ship	1.35	Sum:	1.35	<table> <tr><td></td><td>TS 1</td></tr> <tr><td>Sea ship</td><td>20</td></tr> <tr><td>Sum:</td><td>20</td></tr> </table>		TS 1	Sea ship	20	Sum:	20
	TS 1												
Sea ship	1.35												
Sum:	1.35												
	TS 1												
Sea ship	20												
Sum:	20												
Particulate matter (WTW) combustion related [kilogram]	Distances (WTW) Distances per transport mode [km]												
<table> <tr><td></td><td>TS 1</td></tr> <tr><td>Sea ship</td><td>2.75</td></tr> <tr><td>Sum:</td><td>2.75</td></tr> </table>		TS 1	Sea ship	2.75	Sum:	2.75	<table> <tr><td></td><td>TS 1</td></tr> <tr><td>Sea ship</td><td>75</td></tr> <tr><td>Sum:</td><td>75</td></tr> </table>		TS 1	Sea ship	75	Sum:	75
	TS 1												
Sea ship	2.75												
Sum:	2.75												
	TS 1												
Sea ship	75												
Sum:	75												

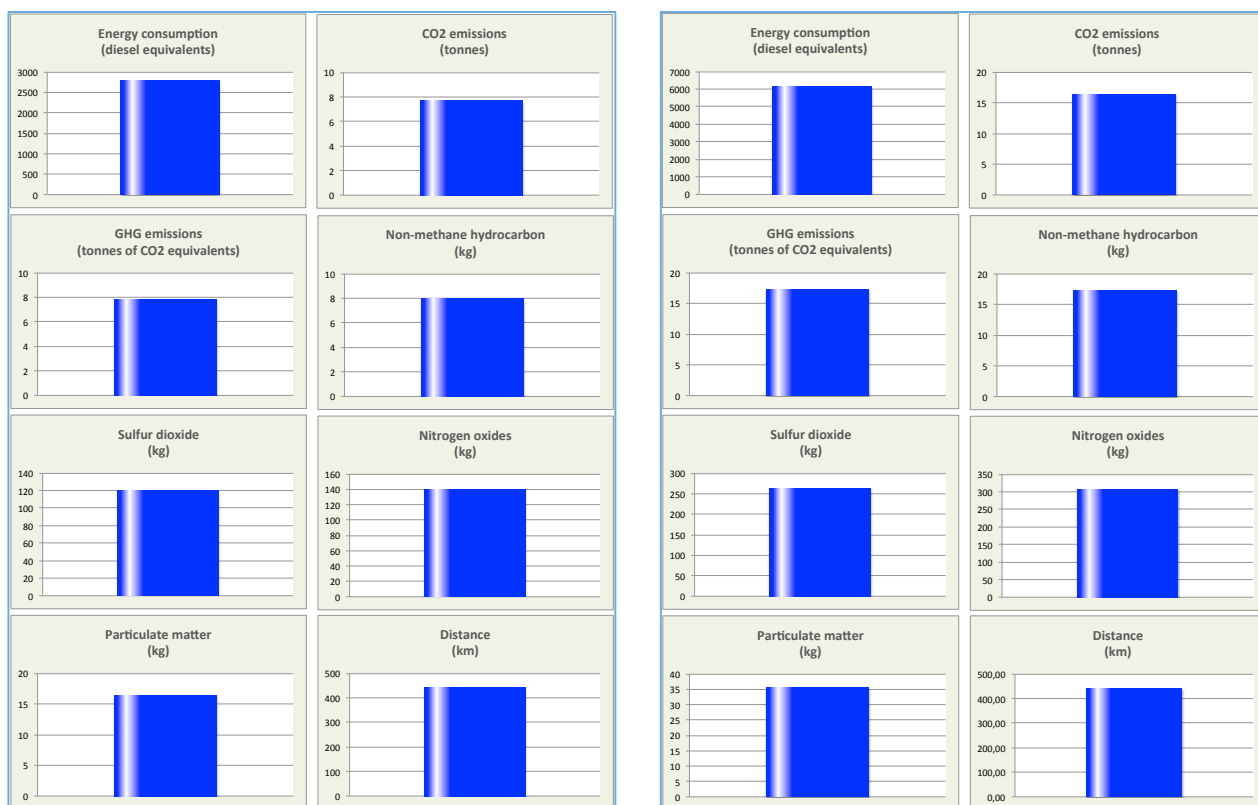
Energy consumption (WTW) Energy resource consumption [Diesel equivalents]	CO2 emissions (WTW) Greenhouse Gas, climate changes [Tonnes]												
<table> <tr><td></td><td>TS 1</td></tr> <tr><td>Sea ship</td><td>1,040</td></tr> <tr><td>Sum:</td><td>1,040</td></tr> </table>		TS 1	Sea ship	1,040	Sum:	1,040	<table> <tr><td></td><td>TS 1</td></tr> <tr><td>Sea ship</td><td>2.86</td></tr> <tr><td>Sum:</td><td>2.86</td></tr> </table>		TS 1	Sea ship	2.86	Sum:	2.86
	TS 1												
Sea ship	1,040												
Sum:	1,040												
	TS 1												
Sea ship	2.86												
Sum:	2.86												
GHG emissions as CO2e (WTW) Climate changes [Tonnes]	Nitrogen oxides (WTW) Acidification, overfertilisation, smog [kilogram]												
<table> <tr><td></td><td>TS 1</td></tr> <tr><td>Sea ship</td><td>2.89</td></tr> <tr><td>Sum:</td><td>2.89</td></tr> </table>		TS 1	Sea ship	2.89	Sum:	2.89	<table> <tr><td></td><td>TS 1</td></tr> <tr><td>Sea ship</td><td>52</td></tr> <tr><td>Sum:</td><td>52</td></tr> </table>		TS 1	Sea ship	52	Sum:	52
	TS 1												
Sea ship	2.89												
Sum:	2.89												
	TS 1												
Sea ship	52												
Sum:	52												
Non-methane hydrocarbon (WTW) Smog, damage caused to so's health [kilogram]	Sulfur dioxide (WTW) Acidification, damage caused to so's health [kilogram]												
<table> <tr><td></td><td>TS 1</td></tr> <tr><td>Sea ship</td><td>2.99</td></tr> <tr><td>Sum:</td><td>2.99</td></tr> </table>		TS 1	Sea ship	2.99	Sum:	2.99	<table> <tr><td></td><td>TS 1</td></tr> <tr><td>Sea ship</td><td>45</td></tr> <tr><td>Sum:</td><td>45</td></tr> </table>		TS 1	Sea ship	45	Sum:	45
	TS 1												
Sea ship	2.99												
Sum:	2.99												
	TS 1												
Sea ship	45												
Sum:	45												
Particulate matter (WTW) combustion related [kilogram]	Distances (WTW) Distances per transport mode [km]												
<table> <tr><td></td><td>TS 1</td></tr> <tr><td>Sea ship</td><td>6.03</td></tr> <tr><td>Sum:</td><td>6.03</td></tr> </table>		TS 1	Sea ship	6.03	Sum:	6.03	<table> <tr><td></td><td>TS 1</td></tr> <tr><td>Sea ship</td><td>75</td></tr> <tr><td>Sum:</td><td>75</td></tr> </table>		TS 1	Sea ship	75	Sum:	75
	TS 1												
Sea ship	6.03												
Sum:	6.03												
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Sum:	75												

Values comparison of energy consumption, GHGs, Air pollutants emissions related to LNG transport by ship to supply La Spezia from Livorno (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right) using HFO as fuel.

Oristano – La Spezia



Oristano - La Spezia route. Source: SeaRoutes.



Charts comparison of energy consumption, GHGs, Air pollutants emissions related to LNG transport by ship to supply La Spezia from Oristano (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right) using HFO as fuel. Data derived by other routes' values parametrized on Oristano – La Spezia route's distance.

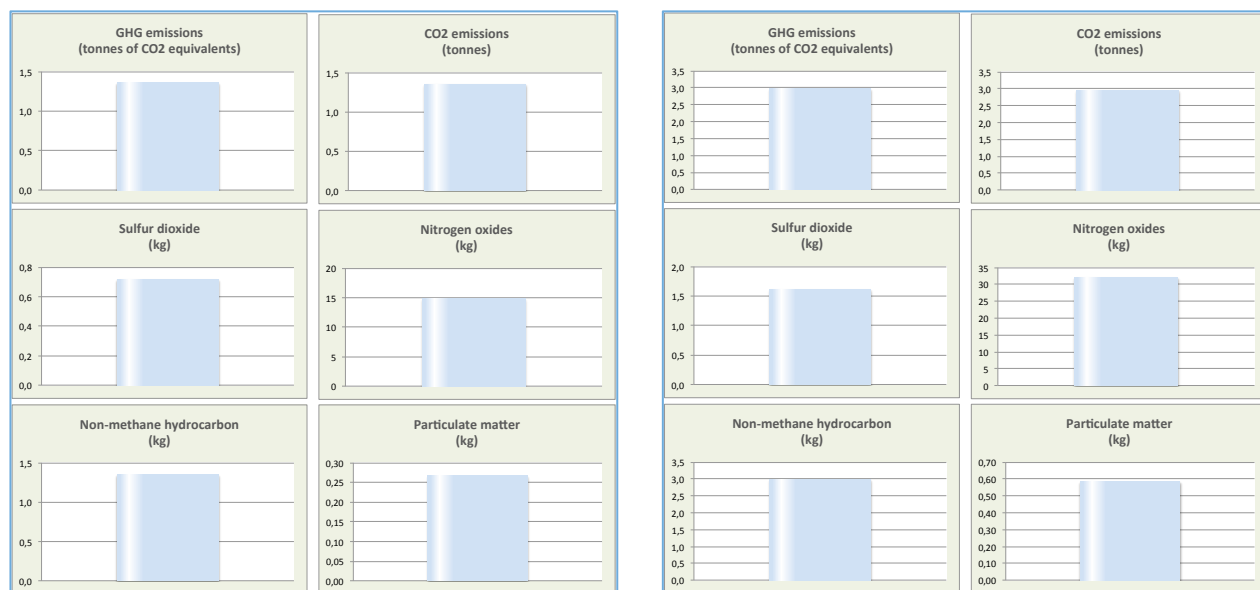
Energy consumption (diesel equivalents)	CO ₂ emissions (tonnes)
2.802,33	7,69
GHG emissions (calculated as tonnes of CO ₂ equivalents)	Non-methane hydrocarbon (kg)
7,78	7,97
Sulfur dioxide (kg)	Nitrogen oxides (kg)
119,54	139,61
Particulate matter (kg)	Distance (km)
16,43	442,57

Energy consumption (diesel equivalents)	CO ₂ emissions (tonnes)
6.132,10	16,43
GHG emissions (calculated as tonnes of CO ₂ equivalents)	Non-methane hydrocarbon (kg)
17,34	17,34
Sulfur dioxide (kg)	Nitrogen oxides (kg)
262,80	306,61
Particulate matter (kg)	Distance (km)
35,59	442,57

Values comparison of energy consumption, GHGs, Air pollutants emissions related to LNG transport by ship to supply La Spezia from Oristano (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right), using HFO as fuel. Data derived by other routes' values parametrized on Oristano – La Spezia route's distance.

B6 – Waterborne transport 2020 scenario. GHGs and air pollutants emissions related to waterborne transport to supply La Spezia with LNG from planned suitable terminals via 2200 m³ or 7500 m³ feeder ships (LNG/conventional fuel comparison).

Livorno – La Spezia

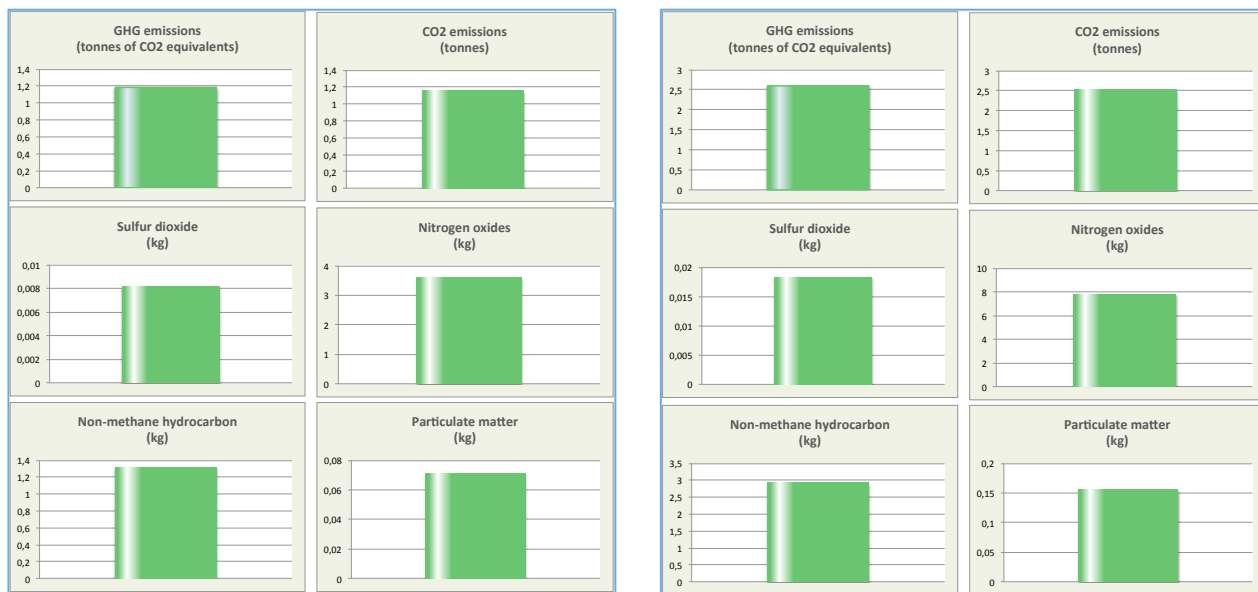


Charts comparison of energy consumption, GHGs and air pollutants emissions related to LNG transport by ship to supply La Spezia from Livorno (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right) using MDO as fuel. Data derived from HFO's values, using MDO's main engine emission factors (values in g/g fuel) of IMO's third GHG Study.

CO ₂ emissions (tonnes)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
1,35	1,36
Non-methane hydrocarbon (kg)	Sulfur dioxide (kg)
1,35	0,72
Nitrogen oxides (kg)	Particulate matter (kg)
14,81	0,27

CO ₂ emissions (tonnes)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
2,95	2,97
Non-methane hydrocarbon (kg)	Sulfur dioxide (kg)
2,99	1,61
Nitrogen oxides (kg)	Particulate matter (kg)
32,08	0,59

Values comparison of energy consumption, GHGs, Air pollutants emissions related to LNG transport by ship to supply La Spezia from Livorno (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right), using MDO as fuel. Data derived from HFO's values, using MDO's main engine emission factors (values in g/g fuel) of IMO's third GHG Study.

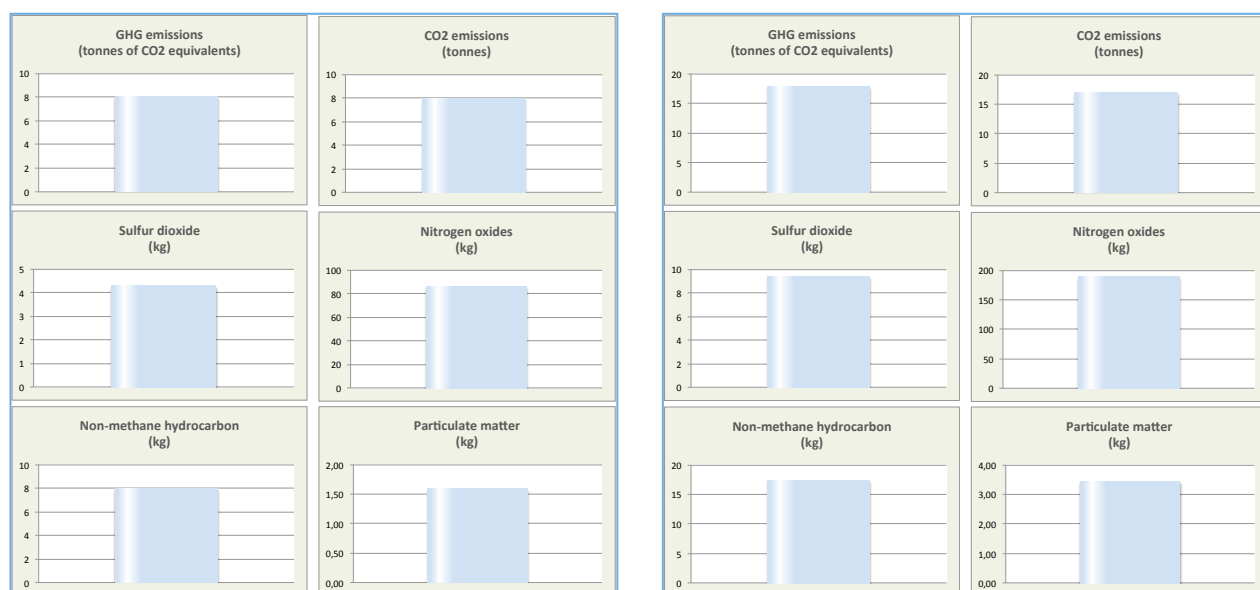


Charts comparison of energy consumption, GHGs and air pollutants emissions related to LNG transport by ship to supply La Spezia from Livorno (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right) using LNG as fuel. Data derived from HFO's values, using LNG's main engine emission factors (values in g/g fuel) of IMO's third GHG Study.

CO ₂ emissions (tonnes)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
1,16	1,19
Non-methane hydrocarbon (kg)	Sulfur dioxide (kg)
1,32	0,01
Nitrogen oxides (kg)	Particulate matter (kg)
3,61	0,07

CO ₂ emissions (tonnes)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
2,53	2,60
Non-methane hydrocarbon (kg)	Sulfur dioxide (kg)
2,92	0,02
Nitrogen oxides (kg)	Particulate matter (kg)
7,82	0,16

Values comparison of energy consumption, GHGs, Air pollutants emissions related to LNG transport by ship to supply La Spezia from Livorno (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right), using LNG as fuel. Data derived from HFO's values, using LNG's main engine emission factors (values in g/g fuel) of IMO's third GHG Study.

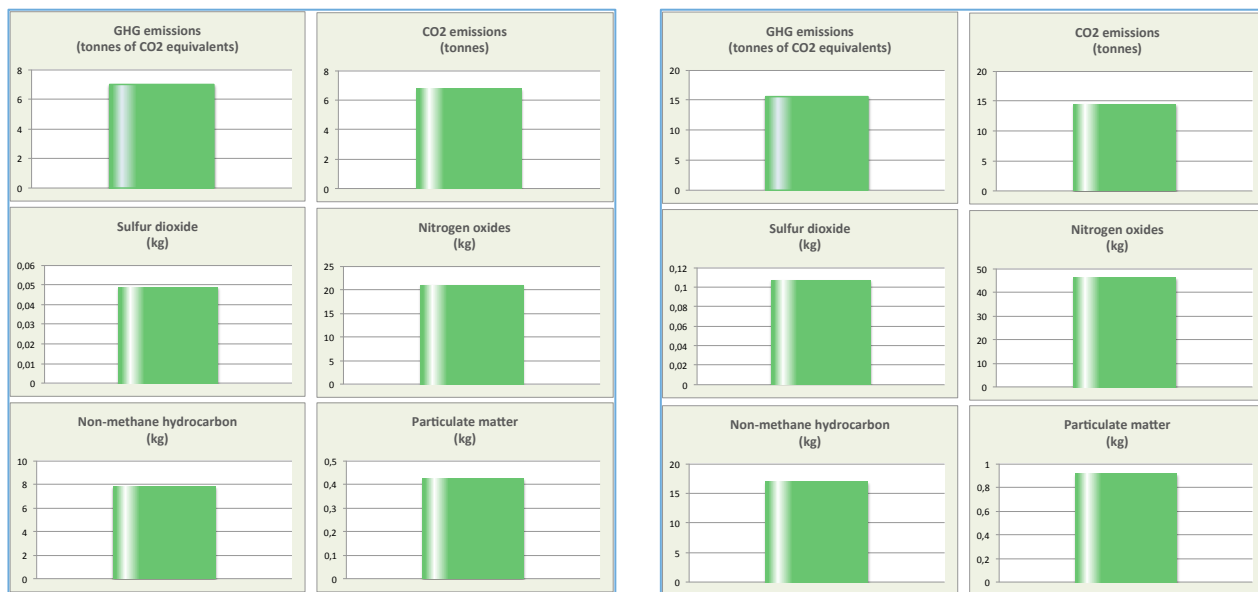


Charts comparison of energy consumption, GHGs and air pollutants emissions related to LNG transport by ship to supply La Spezia from Oristano (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right) using MDO as fuel. Data derived from HFO's values, using MDO's main engine emission factors (values in g/g fuel) of IMO's third GHG Study.

CO ₂ emissions (tonnes)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
7,94	8,01
Non-methane hydrocarbon (kg)	Sulfur dioxide (kg)
7,97	6,43
Nitrogen oxides (kg)	Particulate matter (kg)
86,14	2,40

CO ₂ emissions (tonnes)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
16,95	17,83
Non-methane hydrocarbon (kg)	Sulfur dioxide (kg)
17,34	14,13
Nitrogen oxides (kg)	Particulate matter (kg)
189,18	5,19

Values comparison of energy consumption, GHGs, Air pollutants emissions related to LNG transport by ship to supply La Spezia from Oristano (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right), using HFO as fuel. Data derived from HFO's values, using MDO's main engine emission factors (values in g/g fuel) of IMO's third GHG Study.



Charts comparison of energy consumption, GHGs and air pollutants emissions related to LNG transport by ship to supply La Spezia from Oristano (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right) using LNG as fuel. Data derived from HFO's values, using LNG's main engine emission factors (values in g/g fuel) of IMO's third GHG Study.

CO ₂ emissions (tonnes)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
6,79	7,00
Non-methane hydrocarbon (kg)	Sulfur dioxide (kg)
7,79	0,05
Nitrogen oxides (kg)	Particulate matter (kg)
20,99	0,42

CO ₂ emissions (tonnes)	GHG emissions (calculated as tonnes of CO ₂ equivalents)
14,51	15,58
Non-methane hydrocarbon (kg)	Sulfur dioxide (kg)
16,94	0,11
Nitrogen oxides (kg)	Particulate matter (kg)
46,09	0,92

Values comparison of energy consumption, GHGs, Air pollutants emissions related to LNG transport by ship to supply La Spezia from Oristano (single trip) with a 2200 m³ feeder ship (left) or a 7500 m³ carrier (right), using LNG as fuel. Data derived from HFO's values, using LNG's main engine emission factors (values in g/g fuel) of IMO's third GHG Study.